V. *Discussion of Kew Magnetic Data, especially the Diurnal Inequalities of Horizontal Force and Vertical Force, from Ordinary Days of the Eleven Years* 1890 *to* 1900.

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Contents.

§ 1. In 1901 the development of electrical traction in West London rendered it clear that unless conditions altered in an unexpected direction, no further magnetic records from Kew Observatory would be sufficiently free from artificial disturbances to be an altogether satisfactory medium for the minute study of phenomena such as the regular diurnal variation. The time seemed to have come for taking stock of the records obtained. The measurement of magnetic curves formed no regular part of the work at Kew Observatory until 1890. Prior to that date the Annual Reports contained only a summary of the results of the absolute observations. Since 1890 the programme of work has included the measurement of the magnetic curves for 5 "quiet" days a month. Until a few years ago these days were selected at Greenwich by the Astronomer Royal. Now they are selected under international auspices at De Bilt, the central station of the Meteorological Institute of the Netherlands. Since Kew Observatory was transferred to the Meteorological Office, diurnal inequalities have been published for each month of the year for D (declination) and H (horizontal force). Previously the inequalities published were

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confined to the year, winter (October to March) and summer (April to September). Vertical force (V) and inclination (I) suffer more than D and H from artificial electric currents, and no inequalities have been published for them since 1901.

It was decided to begin by analysing the measurements that had already been made of the "quiet" day curves for an eleven-year period, 1890 to 1900. The necessary labour was almost entirely arithmetical, and it was completed with the aid of the Observatory staff without extraneous financial assistance. The results were embodied in a paper* published in 1903.

It had gradually been recognised that diurnal variations derived from quiet days are not identical with those derived from all days, or from all days but those of large disturbance. It became increasingly obvious that the Kew records would not be fully utilised until the study was extended to other than quiet days. The magnitude of the task was not at first fully realised, and the original programme seems to have embraced all the accumulated data, limiting the enquiry however in the first instance to the declination. At all events the list of Government Grants for 1903 to 1904 includes one of £82 10*s*. "to work up declination (magnetic) results obtained at Kew from 1857 to 1900." The work was practically confined to the 11 years 1890 to 1900, and the grant was exhausted before it was completed.

The curves were divided into "ordinary" and "disturbed." An ordinary day was one in which the general trend of the diurnal variation was clearly recognisable, so that when the trace was oscillatory it could be fairly replaced by a freehand pencil curve of moderate curvature.

It had been the practice, when sensible oscillations occurred on a selected quiet day, to smooth the curve, replacing it by a pencil trace, so the procedure adopted with the ordinary day curves was no innovation. Smoothing was, however, done much more extensively than had been the case with quiet curves, and in some instances it called for considerable exercise of judgment. To secure uniformity, it was always done by myself. Disturbed days were those in which there was so much irregularity that smoothing appeared too arbitrary a process. To a certain extent, no doubt, the allotment of a day to the disturbed list depended on the judge's condition, both physical and mental, at the moment. The attributes of a disturbed day were practically those of "character" 2 days under the international scheme 0 (quiet), 1 (moderately disturbed), and 2 (highly disturbed); and it is only necessary to consult the returns from similarly situated stations to recognise the importance of the personal element in the selection. The choice, in the present case, it should be remembered, was based entirely on the D curves. The total number of days assigned to the disturbed list in the 11 years was 209, or an average of 19 a year. The number varied, however, from 6 in 1890 to 39 in 1896. The results from the ordinary day D curves, excluding a few that were imperfect, were discussed in a paper†

* 'Phil. Trans.,' A, vol. 202, p. 335.

† 'Phil. Trans.,' A, vol. 208, p. 205.

published in 1908. This paper was reprinted with the addition of an Appendix in the 'Collected Researches' of the National Physical Laboratory, vol. 5, 1909. The Appendix contains a list of the 209 disturbed days.

In 1908–9 a further grant of £100 from the Government Grant Committee enabled the measurement to be commenced of all the H and V curves for the period 1890 to 1900. A difficulty at once presented itself. While some of the 209 days, which had been classified as disturbed from consideration of the D curves alone, were quite ordinary so far as the H curves were concerned, other days which had been treated as ordinary from the point of view of the D curves were conspicuously disturbed from the point of view of the H curves. V is a much less disturbed element at Kew than D or H, and many of the V curves from the 209 days classified as disturbed could have been smoothed satisfactorily. The decision reached was to regard the 209 days already selected as representing disturbed conditions for all three elements. Diurnal inequalities were derived from these, and these only, as representative of disturbed conditions. In their case the curves were read absolutely unsmoothed, at exact hours G.M.T. Notwithstanding the large irregularities in individual days, diurnal inequalities were obtained of a fairly regular character.*

§ 2. Coming now to ordinary days, it was decided in the case of H to set aside the 209 days already mentioned, and in addition all days when the H curves were too disturbed to smooth, and to derive inequalities from the remainder. These were smoothed, when it seemed expedient, exactly in the same way as the D curves had been. In the case of V a different procedure was adopted. There was no single month in which a large majority of the curves could not be satisfactorily used without any smoothing. This being so, it seemed best to dispense with smoothing—which everyone admits is open to certain criticisms, while some dispute its necessity—though that entailed omitting a considerable number of days additional to the 209.

The discussion of D results hardly comes under the present memoir, but D enters with H into such quantities as the north and west components (N and W), which of necessity are treated here. Thus particulars of the number of days' traces actually used for the ordinary day D inequalities concern us as well as the corresponding data for D and H. It is simpler to enumerate the days not used than those used. This is done for individual years in Table I., and for the 12 months of the year in Table II. The total number of days in the 11 years, it should be remembered, was 4017.

Natural disturbance was not the sole cause of omission of days. A few of the days—10 in the case of H, 19 in the case of D and V—were omitted owing to imperfections in the records. One cause of imperfection, stoppage of the clock, affected the three elements alike. Another cause, insufficient gas supply, affected all to some extent, but while one trace might be invisible another might be measurable.

* 'Phil. Trans.,' A, vol. 210, p. 271, and 'Collected Researches, National Physical Laboratory,' vol. 7, p. 1.

The H optical arrangements are the best, and it suffered least. The erection in 1892 of a new upper story to the Observatory, with iron girders, produced irregularities on several days, which could not be satisfactorily dealt with. There were various other discontinuities associated with movement of iron in the building, or with changes of sensitiveness in the vertical force magnetograph, which rendered the omission of certain days expedient. But, everything considered, the number of days' trace which could not be utilised was wonderfully small, a fact reflecting credit on the staff, especially Mr. T. W. BAKER, who had charge of the magnetic instruments during the whole period concerned. It was judged important to have a complete set of values of the absolute daily range (maximum less minimum) during the period. The loss of a good many hours' trace necessarily introduces some uncertainty into the daily range, because one at least of the extreme values might fall during the time lost; but in many cases one can be reasonably sure that the range deduced from the part of the trace that is complete is the full range, or at least very approximately so. In all doubtful cases recourse was had to the corresponding Falmouth curves, which were kindly lent by Mr. E. KITTO, then Superintendent of Falmouth Observatory. In a few cases, while the ranges accepted were derived essentially from the Kew curves, a small correction was applied which was based on a comparison of the Kew and Falmouth curves. In a few other instances the range accepted was derived from the Falmouth curve alone. Experience showed that the agreement between Kew and Falmouth ranges was usually so close that the uncertainty thus introduced into monthly or similar mean values must be wholly negligible. Finally, there were two or three cases in which one of the traces during a magnetic storm had gone beyond the limits of registration at the same time both at Kew and Falmouth, or the latter trace was otherwise incomplete. In such a case there was nothing for it but to take the edge of the sheet as representing one of the extreme values. On one occasion, February 14, 1892, the estimate thus made of the D range was not impossibly a very appreciable underestimate, though hardly to the extent of exercising an effect of more than a few tenths of a minute in the monthly mean.

The number of days omitted from the ordinary day diurnal inequalities through imperfections of the trace was so small that we shall not be far wrong if we disregard them when comparing different months or years in Tables I. and II. The curves D, H or V, of the same year were dealt with at one time, while a considerable interval sometimes intervened between the consideration of two successive years. Thus Table II. is probably a more reliable index than Table I. to the fluctuation of disturbance in individual elements. Since, however, the D, H and V curves were considered at widely different times, when their indications in Table I. agree the result may be accepted with some confidence. The two quietest years were undoubtedly 1890 and 1900, the years of lowest sunspot frequency. The last seven months of 1900 contained no single day considered disturbed for any of the elements, and may be accepted as the quietest period of the 11 years. The year of largest

sunspot frequency, 1893, though showing very large regular diurnal variations, was decidedly quieter than the adjacent years.

TABLE I.—Number of Days not included in "Ordinary."

Element.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	11 years.
D	7	26	31	17	21	21	41	16	19	21	8	228
H	6	25	36	14	26	29	45	19	21	22	9	252
V	14	48	53	36	36	39	54	26	28	21	11	366

While 1892 and 1894 contained most of the outstanding magnetic storms, 1896 was remarkable for the persistence of disturbed conditions. A point to be remembered is that it is easier to recognise the general trend of the regular diurnal variation when the range is large than when it is small. Thus a disturbance sufficient to mask the regular diurnal variation when least—*i.e.*, at midwinter, in sunspot minimum—might prove no serious obstacle to smoothing curves at mid-summer near sunspot maximum. Making all due allowance for the increased amplitude of the regular diurnal variation in summer, Table II. shows clearly that the annual variation of disturbance has a well marked double period, with minima at midwinter and midsummer, and maxima in March (or late February) and October. The maximum in Spring is the more prominent of the two.

TABLE II.—Number of Days not included in "Ordinary."

Element.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
D	22	26	32	17	18	7	12	11	19	30	20	14
H	26	26	34	19	18	8	13	18	21	29	24	16
V	40	42	45	31	28	19	23	25	30	37	26	20

The basis on which the curves were treated was largely determined by the fact that the D, H and V curves had to be considered at different times. If a careful consideration of the curves from all three elements had preceded all measurements, a common selection of ordinary days would probably have been made. As it is, a little more disturbance enters into the ordinary day H inequality than into that for V, and a little more into the D inequality than into that for H. This is most to be regretted perhaps in relation to the derived inequalities. The north component (N) and west component (W) inequalities depend on both D and H, while the total force (T) and inclination (I) inequalities depend on H and V. These inequalities, not

improbably, differ slightly from what they would have been if derived from magnetographs recording N, W, T and I directly. The differences, however, cannot be serious, because all the largest disturbances naturally figured on each of the three lists.

§ 3. The full publication of magnetic data normally includes tables of the hourly values of three elements in absolute measure. Besides hourly measurements of the curves, this entails for each element a knowledge of the scale value and of the base value for each day. When a temperature correction is necessary, and the temperature alters sensibly throughout the day, it entails further a knowledge of the temperature coefficient and measurements of the temperature records at each hour. Two months' hourly values of a single element in ordinary type fill a quarto page. Thus full publication of 11 years' data would have filled 198 quarto pages simply with the hourly values of D, H and V. As there was no prospect of publication on this scale, and economy of effort was important, no more was done than was essential for the immediate object in view. So long as one can assume the base value constant for the whole of each day, or can adequately allow for its fluctuation by means of a non-cyclic correction, its value is immaterial, so far as the diurnal inequality is concerned. For simplicity, consider the case where no temperature correction is required. If the scale value can be treated as constant for the whole of a month, as was the case at Kew with rare exceptions, all that is necessary is to take the hourly measurements in millimetres, sum the hourly columns, divide the hourly sums by the number of days in the month, allow for non-cyclic change, find the algebraic excess of each hourly mean value over the corresponding mean for the 24 hours, and convert the inequality thus formed into C.G.S. units, through multiplication by the factor representing the equivalent in force of 1 mm.

When a temperature correction is required, the inequality of temperature for each month can be derived from the hourly measurements of the temperature curves. This is converted into force from a knowledge of the temperature coefficient, and the result is applied with appropriate sign as a correction to the inequality already obtained. There would be a great increase of labour, and no gain in accuracy, so far as the inequality is concerned, if each hourly value of the magnetic curve were corrected for temperature. A second and conclusive reason for not correcting individual hourly values was the fact that continuous records of temperature were not taken in the magnetograph room until 1895. This being so, a course was followed which at least reduced labour to a minimum. During the 11 years no change had been made in the magnetograph room, or in the programme of work done in it or adjacent parts of the building. There was thus no reason to suspect any considerable change in the thermal phenomena in the room, and evidence pointing to the same conclusion was derivable from the 3 or 4 daily readings from mercury thermometers under the glass shades covering the H and V magnets. It was thus decided to calculate mean diurnal inequalities of temperature, utilising the

thermogram measurements made on magnetic quiet days from 1895 to 1900, and these were taken as applying to the whole 11 years. This attributes to each January, for instance, the same diurnal inequality of temperature, while it was no doubt larger in some Januarys than others. This procedure no doubt introduced slight errors into the inequalities for individual months of individual years, but these would tend to disappear in results from groups of years or from the whole 11 years.

The temperature correction of the H magnetograph is about $1{\cdot}7\gamma$ per 1° F., and the range of the temperature diurnal inequality in most months was under 1° F, so a difference of temperature lag of even 1 or 2 hours between the magnet and thermograph would have had little effect. The fluctuations of temperature in the magnetograph room from one day to the next are sometimes much greater than the range of the regular diurnal variation, and the comparison of the readings from the thermograph and mercury thermometer on the one hand, and the corresponding fluctuation in the base values derived from individual absolute observations on the other, afforded grounds for confidence that uncorrected effects of temperature in the H inequalities must be trifling. The V magnet has a much larger temperature coefficient—about $12{\cdot}5\gamma$ for 1° F.—and the range of the regular diurnal variation is considerably less in V than in H. Thus there is more reason to fear uncorrected temperature effect in the V inequalities. It is, however, mainly in the absolute daily range—*i.e.*, the difference between the highest and lowest values throughout the day—that temperature uncertainty comes in. Undoubtedly some individual daily ranges, especially those of V, suffered considerably from this cause. In the case of an element like V at Kew considerably affected by temperature, it is sometimes difficult to recognise the maximum or minimum. If the temperature change in the day has been large, the maximum force may come at quite a different hour from the maximum ordinate. It may be necessary to take half a dozen measurements of the force curve, with the corresponding thermogram measurements, before one can decide. This is especially true of quiet curves—and most V curves are quiet—at seasons when the regular magnetic diurnal variation is small. No temperature corrections, of course, were possible until 1895, and mean results based on a number of days would have been practically useless in dealing with individual days. It was accordingly decided to attempt no temperature corrections to absolute daily ranges, but to derive them from the magnetic curves as if these required no temperature correction.

The neglect of temperature could hardly prejudice one's view of the character of the day as quiet or disturbed, but undoubtedly in a few cases it led to a quiet day being assigned a V range more appropriate to a day of moderate disturbance. The neglect of temperature may even have exerted a slight effect on the estimate of the mean monthly value of the absolute range, as the occurrences of maximum and minimum are much more numerous at certain hours than others, and so the effect of the regular diurnal variation of temperature would not be wholly eliminated.

Non-cyclic Change.

§ 4. In obtaining the diurnal inequalities the non-cyclic (n.c.) change C—*i.e.*, the algebraic excess of the value at the second midnight (hour 24) over that at the first midnight (hour 0)—has been eliminated in the usual way, by applying at hour n the correction $C(12-n)/24$. In the case of D the value of C for each month of the eleven years was given in a previous paper.* The value $-0'\cdot12$ assigned there to February, 1892, should have been $-0'\cdot22$. Allowing for this, the mean values for the year 1892, for the month of February, and for the whole 11 years, become respectively $-0'\cdot031$, $-0'\cdot052$ and $-0'\cdot301$. The change of force perpendicular to the magnetic meridian necessary to alter D by $1'$ varied gradually from $5\cdot29\gamma$ in

TABLE III.—Non-cyclic Change (Unit $0\cdot01\gamma$).

Element.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	11 years.
D	− 7	−15	− 16	−23	−52	+ 4	− 16	−13	−25	−21	+ 9	−16·0
H	+ 2	+68	+200	+69	+90	+84	+118	+80	+63	+61	+42	+79·7
V	−37	−67	− 55	−55	−45	−40	− 25	−29	−30	−50	−28	−42·0

1890 to $5\cdot36\gamma$ in 1900, the mean for the eleven years being $5\cdot32\gamma$. Tables III. and IV. give the mean yearly and monthly values of the n.c. change for the ordinary days in the three elements, those for D being expressed in terms of the equivalent force. Ordinary days, it should be noticed, include the quiet, though, of course, not the disturbed.

TABLE IV.—Non-cyclic Change (Unit $0\cdot01\gamma$).

Element.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
D	− 9	−28	− 41	− 6	+ 7	− 26	− 2	0	−52	− 24	− 15	+ 4
H	+ 41	+97	+202	+ 75	+ 49	+ 6	+ 54	+132	+64	+ 87	+ 84	+67
V	−115	+11	−122	−211	−219	−245	−126	− 2	+98	+214	+141	+73

There is obviously a prevailing tendency for the n.c. change on ordinary days to be negative in D and V and positive in H. The inference that the D and V elements were falling, and the H element rising, would be correct, though unwarranted. The n.c. effect is influenced, of course, by the secular change but it is partly of instrumental

* 'National Physical Laboratory Collected Researches,' vol. V. (Table IIA., p. 48).

origin, and is partly dependent on the type of day dealt with. In the average of the ASTRONOMER ROYAL'S quiet days, D rose $0'{\cdot}044$ ($0{\cdot}23\gamma$), H rose $3{\cdot}34\gamma$ and V fell $0{\cdot}84\gamma$. Thus if all days had been quiet days, D and H would in a single year have increased respectively $16'{\cdot}1$ (86γ) and 1219γ, while V would have fallen 307γ. The real average annual changes during the eleven years were $-5'{\cdot}79$ ($-30{\cdot}8\gamma$) in D, $+25{\cdot}9\gamma$ in H and $-22{\cdot}6\gamma$ in V.

It seems desirable to look into the matter a little more closely. Take first the case of D. There were in the eleven years 209 disturbed and 19 incomplete days. None of the latter, so far as could be judged, were highly disturbed. If we regard them as ordinary, as we are fairly entitled to do, we have 3808 ordinary days. The mean observed n.c. changes on disturbed and ordinary days were respectively $+0'{\cdot}327$ and $-0'{\cdot}0301$. The total n.c. changes were thus $+68'{\cdot}3$ on disturbed and $-114'{\cdot}6$ on ordinary days, leaving a balance of $-46'{\cdot}3$. If all measurements were exact, in the absence of instrumental change, we should expect this balance to agree with the observed secular change, but this at the observed average rate of $-5'{\cdot}79$ per annum amounted to $-63'{\cdot}7$. This leaves $16'{\cdot}4$ unaccounted for, suggesting an instrumental drift of $1'{\cdot}5$ per annum.

In the case of H the 10 incomplete days may reasonably be regarded as ordinary, making a total of 3775 ordinary days. The observed n.c. change on ordinary days averaging $+0{\cdot}797\gamma$, the total n.c. change from the ordinary days of the eleven years comes to $+3009\gamma$. Of the remaining 242 days, 209 were included in the original list of disturbed days. The mean n.c. change for these days was $-13{\cdot}2\gamma$, giving a total n.c. change of -2759γ. The remaining 33 days were included in the subsidiary list of disturbed days, which was made out when the H curves came to be treated. The sum of the n.c. changes on these 33 days was only -24γ. Thus the total n.c. change for the 4017 days of the eleven years was $(+3009-2759-24)\gamma$, or $+226\gamma$. The observed secular change, $+25{\cdot}9 \times 11$ or $+285\gamma$, exceeds this by only 59γ, suggesting the trifling instrumental drift of $-5{\cdot}4\gamma$ per annum.

In the case of V, including the incomplete amongst the ordinary days, we have 3669 of these with an average n.c. change of $-0{\cdot}420\gamma$, giving a total of -1541γ. The 209 disturbed days in the original list contributed $+209 \times 2{\cdot}7\gamma$ or $+564\gamma$, while the 139 disturbed days on the subsidiary list contributed $+304\gamma$. Thus for the whole 4017 days we have a balance of $(-1541+564+304)\gamma$ or -673γ, as compared with a true secular change of $-22{\cdot}6 \times 11\gamma$ or -249γ. This suggests an instrumental drift at the average rate of -39γ per annum.

The chief importance perhaps of these calculations is the light they throw on the trustworthiness of the magnetic curves and measurements. It is unnecessary to emphasise the fact that when instrumental creep is large it is a source of very considerable uncertainty. The results obtained above are not put forward as exact measures of the instrumental creep, but only as showing its order of magnitude and the general fact that it was small. Most of the quiet day curves were measured

many years before the others, and a variety of scales were employed. Then the curves of the 209 originally selected disturbed days were not smoothed, while those of the ordinary days were. Thus in a good many cases, at the midnight common to a disturbed and an ordinary day two readings were taken, at widely different times, one on the unsmoothed curve, the other on a smooth pencil trace. In individual cases these two midnight readings differed considerably, and this of course influenced the balance of the n.c. changes. The difference between the n.c. changes in H on the 209 days of the original disturbed list and the supplementary list of 33 days may appear suspicious, but is easily accounted for. During a large magnetic storm H nearly always shows a slight rise at the start. This is usually followed by a fall, which goes on until the value has diminished below the normal, sometimes much below the normal. There is then a recovery, which may go on at a gradually diminishing rate for some days. The ends and beginnings of storms were represented by a larger proportion of the 33 than of the 209 days. One of the 33 days showed an n.c. change of $+140\gamma$.

In the case of D what the absolute observations suggested was not a real instrumental drift, but occasional small discontinuities due probably to movements of iron in the building. In the case of H there is confirmatory evidence from the base line values that the instrumental creep is in the direction simulating a fall of force, but they suggest -15γ per annum as a more probable estimate than -5γ as found above. In the case of V the instrumental creep in reality seems to fluctuate in direction. When a sensible change of sensitiveness occurred in the course of the year, the tendency to creep seemed more apparent. On individual ordinary days the n.c. change in V is mainly a temperature effect. This may in fact be recognised in the figures given in Table IV. The four months April to July include most of the summer rise of temperature in the magnetograph room, the principal part of the annual fall taking place in the four months September to December. The mean daily n.c. changes during these two groups of months are by Table IV. :

From April to July $-2{\cdot}00\gamma$.
,, September to December $+1{\cdot}32\gamma$.

The two means will naturally include equal or approximately equal contributions from any regular source of drift which is independent of temperature, such for instance as might arise from gradual weakening of the magnet. If we ascribe the difference between the two four months' means obtained above solely to temperature, and take the known temperature coefficient, viz., $12{\cdot}5\gamma$ per 1° F., then assuming the rise and fall of temperature in the two groups of months equal, we find for its amount

$$(3{\cdot}32/2) \times (120/12{\cdot}5) = 16{\cdot}0 \text{ F.}$$

This is not far from the truth. The annual range in reality usually exceeded 20° F., but the rise usually began in February and continued throughout part of August.

The fall of temperature usually continued throughout January, but the readjustments of the magnetograph were usually made in that month leading to special uncertainties in the n.c. changes.

Diurnal Inequalities.

§ 5. The diurnal inequality of a magnetic element is in continuous variation with the season of the year; it also varies according to the development of sunspots, and it depends on the more or less disturbed character of the day. There are most likely other causes of variation; for instance, it seems unlikely that the diurnal variation at a particular station remains wholly unaffected by the secular change in the earth's magnetism. In deciding on the amount of detail advisable in the presentation of the facts, several conflicting considerations have to be allowed for. There is a great deal which in the present state of our knowledge must be regarded as accidental in the magnetic changes on any individual day. If we derive inequalities from the combination of a very limited number of days, a good deal of this "accidental" element will remain uneliminated. If, on the other hand, we combine a large number of days from the same year, the inequality is inevitably a blend of more or less conflicting characteristics. The extent to which this is the case differs at different seasons of the year. There is, for instance, much greater variation in the type and amplitude of the diurnal inequality in the five months November to March than in the five months April to August. If we have at our disposal the data from a large number of years, we can get smooth diurnal inequalities for individual seasons of the year a good deal shorter than a calendar month. This is what we should naturally do if our object were to examine in very minute detail the mode of variation of the diurnal inequality throughout the year. It is, however, open to the objection that it would produce a mass of detail which few readers if any could digest. The object in view moreover might be to some extent defeated by the influence of the sunspot relationship and secular change effects. Considerations of space must also be borne in mind. Diurnal inequalities for each of the 132 months of the eleven years—let alone shorter periods of the year—for H, V, N, W, T and I would have entailed printing an immense mass of figures. As a matter of fact, diurnal inequalities were calculated for H and V from each of the 132 months, but not for the other elements. The H and V ranges from these 132 inequalities are given later, but it was decided to publish for each of these elements only four tables of diurnal inequalities. Thus, in the case of H, Table V. gives the 12 diurnal inequalities obtained by combining all the months of the same name in the 11 years, three diurnal inequalities for the seasons winter (November to February), equinox (March, April, September and October) and summer (May to August), and finally the mean diurnal inequality for the whole year. Table VI. differs from Table V. only in that it is confined to the four years 1892 to 1895 representing large sunspot frequency; for brevity, it is described as referring to sunspot maximum. Table VII. is similarly confined to 1890, 1899, and 1900, and described as

representing sunspot minimum. The mean values of WOLFER's sunspot frequency for the years included in these three tables were respectively 41·7, 75·0 and 7·2. Finally Table VIII. gives for each of the eleven years the mean diurnal inequality for the whole year. Tables IX. to XII. for V correspond exactly with the four tables for H. The n.c. element has been eliminated from all these tables in the way already described. All the inequalities refer to G.M.T. Kew local time is only $1\frac{1}{4}$ minutes after Greenwich, so the employment of local time would have made little difference.

§ 6. The other inequalities were calculated from the H, V and D inequalities, taking the latter as given in my previous paper. We have

$$T^2 = H^2+V^2, \quad \tan I = V/H, \quad N = H\cos D, \quad W = H\sin D \quad . \quad . \quad . \quad (1).$$

Thus if ΔT, ΔH, &c., represent corresponding small departures from the mean values we have

$$\left.\begin{aligned} \Delta T &= \cos I\,\Delta H+\sin I\,\Delta V, \\ \Delta I &= \tfrac{1}{2}\sin 2I\,(\Delta V/V-\Delta H/H), \\ \Delta N &= \cos D\,\Delta H-H\sin D\,\Delta D, \\ \Delta W &= \sin D\,\Delta H+H\cos D\,\Delta D \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

The coefficients of ΔH, ΔV, &c., on the right-hand sides of these equations varied slightly throughout the eleven years, in consequence of the secular change. They were treated as constant throughout individual years, and mean values were taken for inequalities based on the eleven years. In the latter case the formulæ actually used were

$$\left.\begin{aligned} \Delta T &= 0{\cdot}384\,\Delta H+0{\cdot}923\,\Delta V, \\ \Delta I &= 0{\cdot}0277_5\,\Delta V-0{\cdot}0668\,\Delta H, \\ \Delta N &= 0{\cdot}955\,\Delta H-1{\cdot}58\,\Delta D, \\ \Delta W &= 0{\cdot}298\,\Delta H+5{\cdot}08\,\Delta D \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3).$$

where the unit is $1'$ in the case of ΔI and ΔD, and 1γ in the case of the force elements.

Table XIII. gives diurnal inequalities for T. The results for the 12 months are from the 11 years combined. But in addition to a diurnal inequality for the year from the 11 years combined, there are corresponding inequalities for the sunspot maximum and minimum groups of years.

For I two inequality tables are given. Table XIV. contains inequalities for the 12 months and the whole year from the 11 years combined, being derived from Tables V. and IX. It also contains diurnal inequalities for the year from the sunspot maximum and minimum groups of years. Table XV. gives diurnal inequalities for the whole year, from the separate years, based on Tables VIII. and XII.

Tables XVI. and XVII. give monthly and seasonal diurnal inequalities for N and W

from the whole 11 years, and diurnal inequalities for the year from the 11 years and the groups of years of sunspot maximum and minimum.

To save decimals $0{\cdot}1\gamma$ is employed as the unit in the tables relating to elements of force. The extreme hourly values, *i.e.*, the algebraic maximum and minimum, are in heavy type. In addition to the hourly values, the tables give the range or algebraic difference of the extreme hourly values, and the quantity described as A.D. (or average departure from the daily mean). The latter quantity represents the result obtained by dividing by 24 the numerical sum of the differences of the 24 hourly values from their arithmetic mean.

If readings were taken at every minute, instead of every hour of the day, larger values would in most cases be obtained for the range of the inequality, because it must be exceptional for the extreme values to fall at exact hours G.M.T. The under-estimate, however, thus arising is usually very small, as is easily recognised from the shape of the curves representing the inequalities. The value of the A.D. is naturally less affected by the accident of time, and in most cases it probably gives a better idea than the range of the activity of the forces to which the diurnal inequality is due. This is more especially the case when the inequality shows a double daily variation with two maxima and two minima.

§ 7. The inequality data in Table V. are shown graphically in fig. 1. As in other similar cases, the general features are most readily recognised in the curve, while for details recourse is desirable to the numerical data. Fig. 2 shows the H inequalities for the three seasons and the year, contrasting the data for the whole eleven years in Table V. with those for the sunspot maximum and minimum groups of years in Tables VI. and VII.

The composite character of the diurnal inequality in H derived from the whole year is most clearly seen by comparing some of the seasonal data in the morning hours in Table V. At 6h., for instance, while the winter value has its maximum for the day, the summer value falls below the daily mean. The transition from plus to minus in winter does not occur until nearly 9h., while it occurs in equinox shortly after 7 a.m., and in summer shortly after 5 a.m.

The minimum or principal minimum for the day occurs at 10h. from May to September, and at 11h. in the remaining seven months. It is the most constant and dominant feature in the inequality. In the four summer months the afternoon maximum—then the only maximum—is almost equally prominent, but in the other months the afternoon maximum resembles a plateau rather than a peak, and in the winter months the principal maximum occurs in the forenoon.

The forenoon maximum exists also as a secondary maximum in March and October, and even at midsummer the appearance of the curves suggests some influence delaying the plunge to the minimum at 10h. In most months the rise to the afternoon maximum seems to lag somewhat near 4 p.m., and a distinct secondary minimum is then recognisable in the case of January.

TABLE V.—Diurnal Inequality in Horizontal

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
January . . .	+ 3	+ 7	+ 19	+ 35	+ 57	+ **70**	+ 67	+ 39	− 17	− 63	− **90**	− 70
February . .	+ 17	+ 14	+ 16	+ 30	+ 50	+ 67	+ **69**	+ 41	− 21	− 78	−**112**	− 93
March . . .	+ 46	+ 43	+ 45	+ 45	+ 58	+ **63**	+ 44	− 16	−109	−181	−**204**	−153
April . . .	+ 74	+ 56	+ 50	+ 47	+ 46	+ 40	− 2	− 78	−178	−262	−**271**	−202
May	+ 60	+ 46	+ 36	+ 26	+ 8	− 31	− 97	−164	−213	−**235**	−214	−153
June . . .	+ 52	+ 38	+ 33	+ 28	+ 6	− 47	−115	−181	−235	−**255**	−224	−162
July	+ 56	+ 42	+ 32	+ 25	+ 2	− 44	−107	−175	−235	−**262**	−238	−167
August . . .	+ 81	+ 62	+ 57	+ 41	+ 15	− 23	− 98	−183	−247	−**266**	−225	−137
September . .	+ 78	+ 67	+ 61	+ 61	+ 55	+ 26	− 32	−117	−202	−**247**	−227	−135
October . .	+ 62	+ 60	+ 64	+ 74	+ **86**	+ 80	+ 49	− 26	−130	−207	−**213**	−165
November . .	+ 18	+ 22	+ 34	+ 48	+ 65	+ **75**	+ 65	+ 27	− 48	−105	−**122**	− 94
December . .	− 2	+ 3	+ 17	+ 34	+ 56	+ **72**	+ 67	+ 48	+ 6	− 41	− **64**	− 63
Winter . . .	+ 9	+ 12	+ 22	+ 37	+ 57	+ **71**	+ 67	+ 39	− 20	− 72	− **97**	− 80
Equinox . .	+ 65	+ 57	+ 55	+ 57	+ 61	+ 52	+ 15	− 59	−155	−224	−**229**	−164
Summer . .	+ 62	+ 47	+ 39	+ 30	+ 8	− 36	−104	−176	−233	−**255**	−225	−155
Year . . .	+ 45	+ 38	+ 39	+ 41	+ 42	+ 29	− 8	− 65	−136	−**184**	−**184**	−133

TABLE VI.—Diurnal Inequality in Horizontal Force,

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
January . .	+ 21	+ 24	+ 36	+ 52	+ 71	+ **82**	+ 74	+ 38	− 30	− 93	−**125**	−111
February . .	+ 24	+ 23	+ 25	+ 39	+ 66	+ **86**	+ 81	+ 39	− 38	−107	−**149**	−128
March . . .	+ 55	+ 55	+ 62	+ 64	+ 74	+ 77	+ 43	− 27	−137	−231	−**265**	−197
April . . .	+ 97	+ 72	+ 64	+ 58	+ 52	+ 45	− 15	−104	−224	−332	−**335**	−250
May	+ 70	+ 50	+ 45	+ 34	+ 13	− 27	−104	−188	−254	−**285**	−269	−194
June . . .	+ 61	+ 46	+ 41	+ 36	+ 8	− 59	−149	−241	−311	−**324**	−275	−194
July	+ 69	+ 55	+ 38	+ 29	− 6	− 61	−132	−212	−288	−**328**	−307	−219
August . . .	+ 99	+ 77	+ 72	+ 56	+ 16	− 21	−115	−215	−292	−**318**	−282	−188
September . .	+ 95	+ 84	+ 73	+ 72	+ 64	+ 34	− 33	−133	−233	−**269**	−253	−163
October . .	+ 82	+ 84	+ 89	+ 99	+**111**	+100	+ 59	− 34	−159	−261	−**272**	−212
November . .	+ 35	+ 46	+ 58	+ 64	+ 81	+ **93**	+ 81	+ 29	− 65	−131	−**163**	−137
December . .	+ 9	+ 10	+ 24	+ 44	+ 67	+ **84**	+ 74	+ 53	0	− 58	− 94	− **95**
Winter . . .	+ 22	+ 26	+ 36	+ 50	+ 71	+ **86**	+ 77	+ 40	− 33	− 97	−**133**	−118
Equinox . .	+ 82	+ 74	+ 72	+ 73	+ 75	+ 64	+ 13	− 75	−188	−273	−**281**	−205
Summer . .	+ 75	+ 57	+ 49	+ 39	+ 8	− 42	−125	−214	−286	−**314**	−283	−199
Year . . .	+ 60	+ 52	+ 52	+ 54	+ 51	+ 36	− 11	− 83	−169	−228	−**232**	−174

Force, from 11 Years. (Unit 0·1γ.)

13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.	Range.	A.D.
− 29	− 5	− 7	− 16	− 12	0	+ 5	+ 4	0	+ 1	+ 1	+ 1	160	25·8
− 57	− 27	− 16	− 15	− 10	+ 1	+ 10	+ 21	+ 25	+ 24	+ 25	+ 21	181	35·8
− 87	− 32	+ 6	+ 21	+ 23	+ 37	+ 53	+ 60	+ 62	**+ 63**	+ 60	+ 53	267	65·2
−125	− 47	+ 10	+ 50	+ 83	+105	**+112**	+110	+103	+ 98	+ 93	+ 89	383	97·1
− 93	− 32	+ 25	+ 74	+123	+154	**+164**	+143	+120	+100	+ 86	+ 72	399	102·9
− 95	− 21	+ 46	+ 90	+133	+165	**+183**	+168	+136	+107	+ 83	+ 67	438	111·3
− 91	− 14	+ 53	+ 95	+130	+156	**+169**	+162	+137	+111	+ 90	+ 71	431	111·0
− 58	+ 1	+ 40	+ 59	+ 80	+110	**+136**	**+136**	+127	+111	+ 95	+ 87	402	103·1
− 58	− 14	+ 5	+ 18	+ 35	+ 64	+ 89	+ 97	+ 95	+ 96	**+ 98**	+ 86	345	86·0
−103	− 51	− 19	− 6	+ 16	+ 40	+ 53	+ 60	+ 65	+ 71	+ 72	+ 68	299	76·7
− 62	− 40	− 26	− 8	+ 12	+ 18	+ 21	+ 22	+ 20	+ 20	+ 18	+ 19	197	42·0
− 43	− 30	− 23	− 15	− 5	− 2	− 1	− 5	− 4	− 3	− 1	− 2	136	25·3
− 48	− 26	− 18	− 14	− 4	+ 4	+ 9	+ 10	+ 10	+ 11	+ 11	+ 10	168	31·6
− 93	− 36	0	+ 21	+ 39	+ 61	+ 77	**+ 82**	+ 81	**+ 82**	+ 81	+ 74	311	80·0
− 84	− 17	+ 41	+ 80	+117	+146	**+163**	+152	+130	+107	+ 89	+ 74	418	107·1
− 75	− 26	+ 8	+ 29	+ 51	+ 71	**+ 83**	+ 81	+ 74	+ 67	+ 60	+ 53	267	67·6

from Sunspot Maximum Years. (Unit 0·1γ.)

13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.	Range.	A.D.
− 66	− 28	− 22	− 23	− 9	+ 8	+ 15	+ 16	+ 18	+ 19	+ 18	+ 15	207	42·2
− 87	− 52	− 25	− 10	+ 5	+ 18	+ 22	+ 30	+ 35	+ 34	+ 39	+ 30	235	49·7
−115	− 38	+ 10	+ 30	+ 35	+ 56	+ 71	+ 77	**+ 80**	+ 78	+ 77	+ 66	345	84·2
−154	− 64	+ 6	+ 64	+102	+132	**+149**	+147	+133	+128	+117	+112	484	123·2
−124	− 49	+ 24	+ 88	+149	+188	**+201**	+176	+151	+125	+100	+ 82	486	124·6
−109	− 15	+ 68	+126	+175	+210	**+226**	+207	+168	+129	+ 97	+ 79	550	139·7
−124	− 27	+ 64	+125	+179	+209	**+219**	+202	+171	+137	+115	+ 92	547	142·0
− 98	− 8	+ 48	+ 78	+103	+137	+167	**+168**	+158	+137	+117	+105	486	128·1
− 81	− 32	− 5	+ 17	+ 37	+ 74	+102	+112	+109	+113	**+114**	+100	383	100·1
−135	− 71	− 25	− 1	+ 23	+ 52	+ 63	+ 75	+ 81	+ 84	+ 84	+ 85	383	97·5
−106	− 67	− 40	− 16	+ 8	+ 19	+ 29	+ 33	+ 42	+ 40	+ 34	+ 33	256	60·4
− 74	− 52	− 35	− 15	− 2	+ 2	+ 4	+ 8	+ 8	+ 13	+ 13	+ 12	179	35·4
− 83	− 50	− 30	− 16	0	+ 12	+ 17	+ 22	+ 26	+ 27	+ 26	+ 22	219	46·7
−121	− 51	− 4	+ 28	+ 49	+ 78	+ 96	**+103**	+101	+101	+ 98	+ 91	384	99·8
−114	− 25	+ 51	+104	+151	+186	**+203**	+188	+162	+132	+107	+ 90	517	133·5
−106	− 42	+ 6	+ 39	+ 67	+ 92	**+106**	+104	+ 96	+ 86	+ 77	+ 68	338	87·1

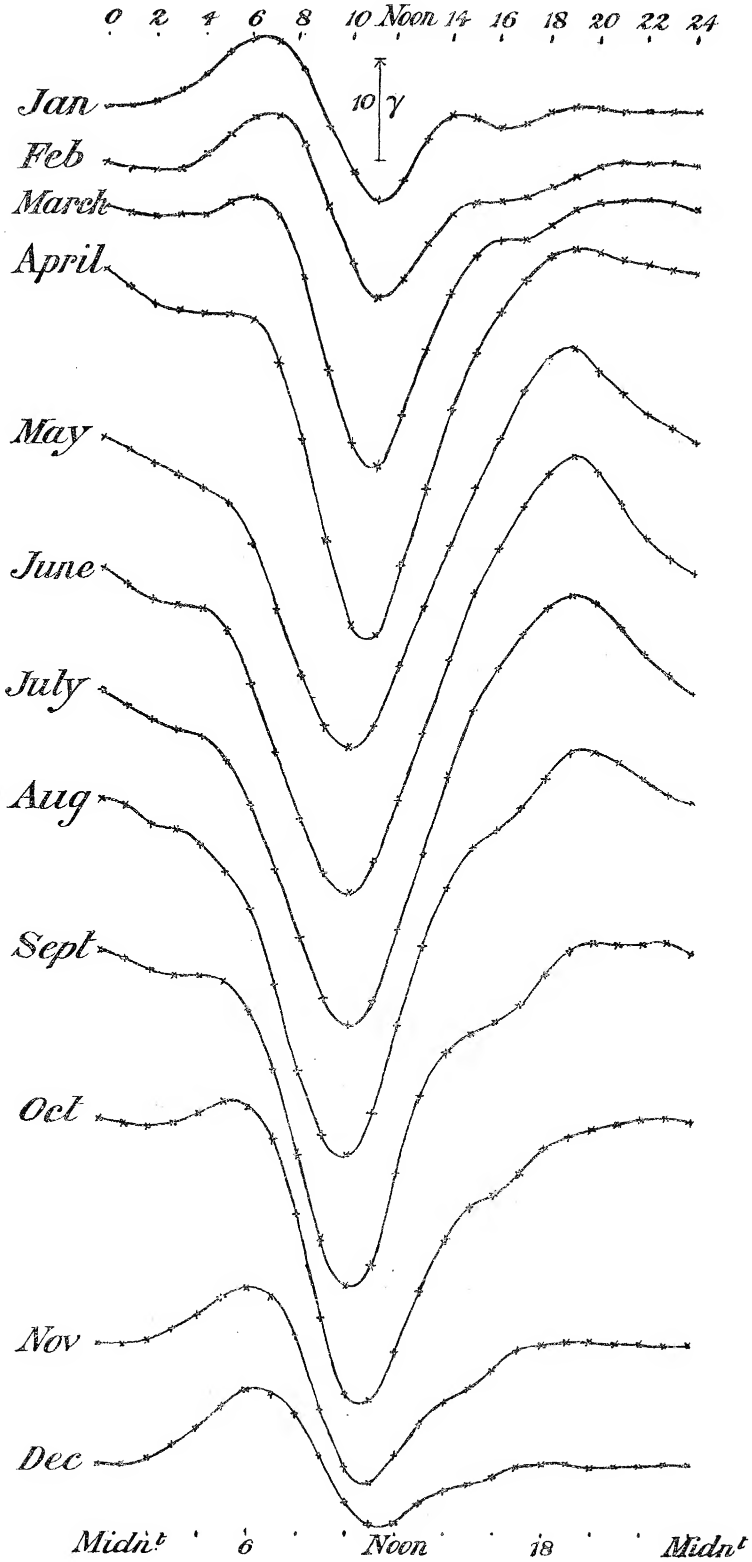

Fig. 1. Horizontal force. 11 years.

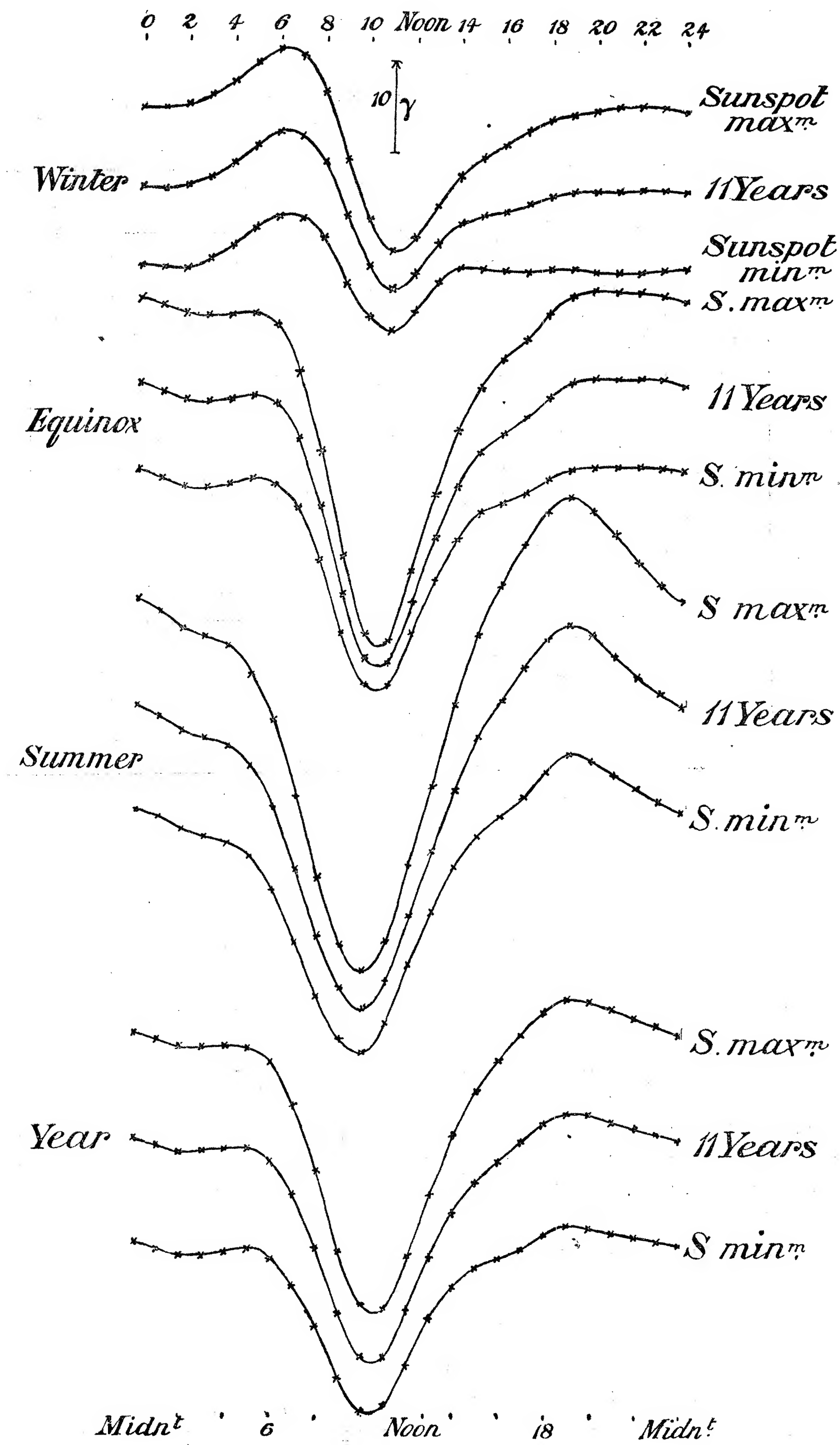

Fig. 2. Horizontal force.

TABLE VII.—Diurnal Inequality in Horizontal Force,

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
January . .	− 16	− 17	− 5	+ 9	+ 32	+ 47	+ **49**	+ 31	− 12	− 30	− **47**	− 17
February . .	+ 16	+ **7**	+ 10	+ 20	+ 34	+ 48	+ **53**	+ 36	− 20	− 61	− **88**	− 69
March . . .	+ 31	+ 27	+ 29	+ 27	+ 41	+ **48**	+ 41	− 10	− 89	−143	−**157**	−112
April . . .	+ 55	+ 37	+ 29	+ 27	+ 28	+ 26	+ 5	− 47	−129	−195	−**198**	−145
May	+ 51	+ 42	+ 33	+ 23	+ **7**	− 30	− 84	−137	−175	−**187**	−160	−108
June . . .	+ 45	+ 31	+ 24	+ 27	+ 15	− 22	− 76	−132	−182	−**208**	−185	−134
July	+ 48	+ 32	+ 22	+ 18	+ 5	− 32	− 89	−146	−194	−**204**	−173	−104
August . . .	+ 63	+ 53	+ 44	+ 30	+ 11	− 27	− 87	−154	−201	−**213**	−167	− 86
September .	+ 55	+ 46	+ 43	+ 49	+ 50	+ 24	− 25	− 94	−168	−**216**	−195	−105
October . .	+ 42	+ 43	+ 47	+ 55	+ **68**	+ 63	+ 39	− 21	− 98	−154	−**159**	−127
November . .	+ 5	+ 4	+ 18	+ 35	+ 53	+ **58**	+ 44	+ 17	− 41	− 84	− **87**	− 65
December . .	− 7	− 1	+ 12	+ 29	+ 50	+ **63**	+ 62	+ 47	+ 7	− 33	− **45**	− 39
Winter . . .	− 1	− 2	+ 9	+ 23	+ 42	+ **54**	+ 52	+ 33	− 17	− 52	− **67**	− 48
Equinox . .	+ 46	+ 38	+ 37	+ 40	+ 47	+ 40	+ 15	− 43	−121	−**177**	−**177**	−122
Summer . .	+ 52	+ 39	+ 31	+ 24	+ 9	− 28	− 84	−142	−188	−**203**	−171	−108
Year . . .	+ 32	+ 25	+ 25	+ 29	+ 33	+ 22	− 6	− 51	−108	−**144**	−138	− 93

TABLE VIII.—Diurnal Inequality in Horizontal

Year.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
1890	+ 34	+ 25	+ 24	+ 29	+ 33	+ 19	− 10	− 52	−109	−**142**	−133	− 84
1891	+ 42	+ 37	+ 38	+ 43	+ 43	+ 25	− 11	− 67	−135	−**182**	−182	−134
1892	+ 61	+ 51	+ 49	+ 49	+ 39	+ 26	− 18	− 89	−174	−**232**	−231	−166
1893	+ 64	+ 56	+ 55	+ 59	+ 62	+ 41	− 9	− 86	−178	−244	−**251**	−187
1894	+ 60	+ 51	+ 55	+ 55	+ 54	+ 40	− 8	− 82	−169	−230	−**234**	−186
1895	+ 55	+ 51	+ 49	+ 52	+ 51	+ 37	− 10	− 75	−156	−206	−**213**	−157
1896	+ 44	+ 36	+ 36	+ 36	+ 41	+ 29	− 3	− 56	−129	−180	−**184**	−135
1897	+ 41	+ 33	+ 33	+ 37	+ 39	+ 32	+ 3	− 50	−110	−**160**	−159	−114
1898	+ 38	+ 32	+ 31	+ 34	+ 35	+ 21	− 10	− 61	−117	−**152**	−149	−105
1899	+ 36	+ 28	+ 27	+ 30	+ 35	+ 26	− 5	− 55	−117	−**154**	−147	−102
1900	+ 27	+ 23	+ 25	+ 29	+ 31	+ 22	− 3	− 46	−100	−**137**	−136	− 92

from Sunspot Minimum Years. (Unit 0·1γ.)

13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.	Range.	A.D.
+ 20	+ 32	+ 21	+ 1	− 17	− 10	− 9	− 9	− 14	− 14	− 12	− 11	96	20·1
− 30	− 2	+ 1	− 5	− 10	− 7	+ 2	+ 11	+ 15	+ 10	+ 15	+ 17	141	24·5
− 55	− 13	+ 17	+ 23	+ 17	+ 24	+ 34	+ 43	+ 44	+ 47	+ 44	+ 41	205	48·2
− 92	− 27	+ 22	+ 41	+ 60	+ 70	+ **75**	+ **75**	+ **75**	+ 71	+ 68	+ 69	273	69·4
− 58	− 11	+ 26	+ 55	+ 89	+114	+**123**	+105	+ 92	+ 76	+ 66	+ 54	310	79·4
− 72	− 13	+ 31	+ 60	+ 89	+119	+**140**	+128	+106	+ 86	+ 68	+ 55	348	85·3
− 48	+ 5	+ 42	+ 61	+ 78	+104	+**123**	+**123**	+103	+ 90	+ 73	+ 61	327	82·4
− 22	+ 15	+ 34	+ 39	+ 46	+ 76	+**108**	+105	+101	+ 91	+ 77	+ 70	321	80·0
− 35	− 1	+ 13	+ 19	+ 31	+ 55	+ 79	+ **80**	+ 74	+ 74	+ **80**	+ 68	296	70·0
− 79	− 38	− 14	− 2	+ 16	+ 35	+ 42	+ 42	+ 47	+ 53	+ 50	+ 46	227	57·5
− 32	− 16	− 8	+ 6	+ 17	+ 21	+ 19	+ 11	+ 6	+ 6	+ 7	+ 8	145	27·8
− 14	− 11	− 13	− 11	− 4	− 3	− 13	− 23	− 19	− 15	− 9	− 9	108	22·5
− 14	+ 1	0	− 2	− 3	0	0	− 3	− 3	− 3	0	+ 1	121	17·9
− 65	− 20	+ 10	+ 20	+ 31	+ 46	+ 58	+ 60	+ 60	+ **61**	+ 60	+ 56	238	60·4
− 50	− 1	+ 33	+ 54	+ 75	+103	+**123**	+115	+100	+ 86	+ 71	+ 60	326	81·3
− 43	− 7	+ 14	+ 24	+ 34	+ 50	+ **60**	+ 58	+ 53	+ 48	+ 44	+ 39	204	49·2

Force, from Individual Years. (Unit 0·1γ.)

13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.	Range.	A.D.
− 34	0	+ 17	+ 29	+ 34	+ 48	+ **56**	+ 51	+ 47	+ 41	+ 39	+ 38	198	47·0
− 73	− 20	+ 18	+ 35	+ 58	+ 76	+ **80**	+ 76	+ 66	+ 60	+ 57	+ 50	262	67·0
−100	− 36	+ 10	+ 43	+ 72	+ 95	+**107**	+105	+ 99	+ 89	+ 81	+ 71	339	87·2
−110	− 38	+ 14	+ 47	+ 71	+ 92	+**105**	+104	+ 95	+ 87	+ 79	+ 73	356	92·0
−116	− 53	− 4	+ 35	+ 70	+101	+**114**	+112	+102	+ 89	+ 78	+ 66	348	90·2
− 97	− 41	+ 2	+ 30	+ 55	+ 81	+ **97**	+ 96	+ 88	+ 80	+ 71	+ 61	310	79·6
− 77	− 29	+ 6	+ 27	+ 48	+ 69	+ 82	+ **84**	+ 75	+ 68	+ 59	+ 53	268	66·1
− 67	− 32	− 6	+ 12	+ 40	+ 62	+ **76**	+ 74	+ 63	+ 56	+ 53	+ 43	236	58·1
− 57	− 18	+ 3	+ 18	+ 39	+ 54	+ 71	+ **72**	+ 66	+ 58	+ 52	+ 45	224	55·8
− 55	− 16	+ 8	+ 19	+ 36	+ 54	+ **66**	+ 65	+ 61	+ 59	+ 55	+ 47	220	54·3
− 41	− 4	+ 17	+ 24	+ 33	+ 48	+ **59**	+ 57	+ 50	+ 44	+ 38	+ 32	196	46·6

TABLE IX.—Diurnal Inequality in Vertical

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
January . .	− 6	− 10	− 16	− 18	− 19	− 20	− 23	− 25	− 30	− 36	− 33	**− 39**
February . .	− 8	− 20	− 24	− 19	− 21	− 23	− 23	− 23	− 31	− 61	**− 70**	− 61
March . . .	− 6	− 15	− 21	− 20	− 17	− 15	− 6	− 10	− 44	− 90	−126	**−127**
April . . .	+ 4	− 8	− 14	− 15	− 8	+ 2	+ 10	− 4	− 51	−106	−153	**−167**
May	+ 7	0	− 2	+ 2	+ 7	+ 6	− 10	− 35	− 85	−149	**−194**	−190
June . . .	− 5	− 19	− 20	− 14	− 8	− 16	− 25	− 51	− 84	−129	**−162**	−154
July	− 3	− 25	− 33	− 30	− 21	− 34	− 41	− 55	− 85	−115	−151	**−155**
August . . .	− 2	− 10	− 10	− 8	+ 4	+ 9	+ 6	− 13	− 59	−106	−143	**−147**
September . .	− 2	− 9	− 16	− 18	− 21	− 15	− 11	− 28	− 66	−106	**−127**	−122
October . .	− 8	− 14	− 23	− 24	− 26	− 25	− 15	− 10	− 31	− 72	**− 98**	− 89
November . .	− 15	− 20	− 23	− 23	− 22	− 27	− 31	− 25	− 31	**− 54**	**− 54**	− 37
December . .	− 3	− 12	− 15	− 17	− 13	− 12	− 13	− 16	− 23	**− 36**	− 34	− 35
Winter . . .	− 8	− 16	− 20	− 19	− 19	− 20	− 23	− 22	− 29	− 47	**− 48**	− 43
Equinox . .	− 3	− 12	− 18	− 19	− 18	− 13	− 6	− 13	− 48	− 94	**−126**	**−126**
Summer . .	− 1	− 13	− 16	− 13	− 5	− 9	− 17	− 38	− 78	−125	**−163**	−162
Year	− 4	− 14	− 18	− 17	− 14	− 14	− 15	− 25	− 52	− 88	**−112**	−110

TABLE X.—Diurnal Inequality in Vertical Force,

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
January . .	− 4	− 10	− 20	− 24	− 25	− 24	− 27	− 28	− 34	− 45	− 41	**− 50**
February . .	− 6	− 21	− 24	− 20	− 26	− 31	− 27	− 23	− 37	− 78	**− 88**	− 74
March . . .	− 17	− 22	− 34	− 30	− 22	− 18	0	0	− 38	− 90	−130	**−133**
April . . .	− 5	− 18	− 22	− 21	− 8	+ 8	+ 20	+ 7	− 46	−105	−160	**−178**
May	0	− 5	− 7	+ 3	+ 13	+ 13	− 5	− 35	− 91	−168	**−223**	−215
June . . .	− 16	− 28	− 28	− 18	− 6	− 10	− 20	− 53	− 89	−146	**−185**	−180
July	− 9	− 39	− 49	− 47	− 36	− 45	− 56	− 73	−102	−135	−171	**−178**
August . . .	− 5	− 13	− 15	− 13	+ 2	+ 10	+ 8	− 10	− 59	−115	−153	**−156**
September . .	− 5	− 11	− 18	− 23	− 26	− 19	− 13	− 31	− 73	−116	**−138**	−130
October . .	− 12	− 22	− 34	− 36	− 39	− 38	− 24	− 16	− 34	− 83	**−112**	−105
November . .	− 21	− 28	− 30	− 31	− 29	− 33	− 36	− 24	− 30	− 59	**− 62**	− 45
December . .	− 12	− 25	− 26	− 26	− 22	− 19	− 19	− 19	− 26	− 43	**− 46**	− 42
Winter . . .	− 11	− 21	− 25	− 25	− 26	− 27	− 27	− 24	− 32	− 56	**− 59**	− 53
Equinox . .	− 10	− 18	− 27	− 28	− 24	− 17	− 4	− 10	− 48	− 99	−135	**−136**
Summer . .	− 8	− 21	− 25	− 19	− 7	− 8	− 18	− 43	− 85	−141	**−183**	−182
Year	− 9	− 20	− 26	− 24	− 19	− 17	− 17	− 25	− 55	− 99	**−126**	−124

Force, from 11 Years. (Unit 0·1γ.)

13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.	Range.	A.D.
− 23	+ 13	+ 33	+ 34	+ **40**	+ 39	+ 38	+ 38	+ 33	+ 18	+ 10	+ 2	79	24·8
− 44	− 4	+ 38	+ 60	+ **68**	+ 66	+ 57	+ 53	+ 41	+ 27	+ 16	+ 6	138	36·0
− 93	− 30	+ 38	+ 84	+ **103**	+ 98	+ 89	+ 78	+ 63	+ 44	+ 19	+ 2	230	51·6
−132	− 51	+ 16	+ 59	+ 96	+ **116**	+ 110	+ 97	+ 77	+ 58	+ 40	+ 23	283	59·0
−138	− 61	+ 9	+ 67	+ 115	+ **142**	+ 139	+ 125	+ 98	+ 70	+ 50	+ 28	336	72·0
−109	− 43	+ 17	+ 75	+ 120	+ 141	+ **142**	+ 127	+ 98	+ 64	+ 37	+ 19	304	70·0
−120	− 50	+ 24	+ 81	+ 128	+ **154**	+ 149	+ 134	+ 106	+ 75	+ 45	+ 22	309	76·5
−107	− 38	+ 31	+ 74	+ 101	+ **106**	+ 89	+ 80	+ 63	+ 45	+ 25	+ 9	253	53·5
− 78	− 16	+ 39	+ 81	+ **94**	+ **94**	+ 93	+ 82	+ 67	+ 50	+ 30	+ 8	221	53·0
− 57	− 11	+ 38	+ 69	+ **72**	+ **72**	+ 67	+ 65	+ 57	+ 38	+ 20	+ 6	170	42·0
− 15	+ 29	+ 53	+ **61**	+ 58	+ 52	+ 46	+ 38	+ 33	+ 15	+ 2	− 9	115	32·2
− 22	+ 5	+ 21	+ 32	+ **35**	+ 34	+ 31	+ 29	+ 28	+ 21	+ 13	+ 5	71	21·0
− 26	+ 11	+ 36	+ 47	+ **50**	+ 48	+ 43	+ 40	+ 34	+ 20	+ 10	+ 1	98	28·3
− 90	− 27	+ 33	+ 73	+ 91	+ **95**	+ 90	+ 81	+ 66	+ 47	+ 27	+ 10	221	51·1
−118	− 48	+ 20	+ 74	+ 116	+ **136**	+ 130	+ 117	+ 91	+ 64	+ 39	+ 19	299	67·2
− 78	− 21	+ 30	+ 65	+ 86	+ **93**	+ 87	+ 79	+ 64	+ 44	+ 26	+ 10	205	48·6

from Sunspot Maximum Years. (Unit 0·1γ.)

13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.	Range.	A.D.
− 35	+ 9	+ 34	+ 43	+ 49	+ 49	+ **51**	+ 49	+ 44	+ 23	+ 12	+ 4	101	30·6
− 52	− 3	+ 45	+ 69	+ **82**	+ 77	+ 71	+ 64	+ 47	+ 29	+ 19	+ 7	170	42·5
− 98	− 30	+ 44	+ 97	+ **121**	+ 117	+ 100	+ 85	+ 63	+ 38	+ 7	− 10	254	56·0
−145	− 57	+ 13	+ 67	+ 107	+ **126**	+ 120	+ 106	+ 83	+ 57	+ 37	+ 14	304	63·8
−159	− 78	+ 6	+ 72	+ 135	+ **173**	+ 164	+ 146	+ 110	+ 76	+ 51	+ 24	396	82·2
−129	− 51	+ 24	+ 89	+ 146	+ **169**	+ 164	+ 142	+ 109	+ 68	+ 35	+ 13	354	79·9
−141	− 53	+ 34	+ 104	+ 162	+ **193**	+ 184	+ 164	+ 127	+ 89	+ 52	+ 25	371	94·5
−117	− 36	+ 34	+ 86	+ **114**	+ 114	+ 95	+ 84	+ 64	+ 46	+ 24	+ 11	270	57·7
− 82	− 16	+ 48	+ 91	+ **107**	+ 105	+ 102	+ 89	+ 72	+ 52	+ 30	+ 5	245	58·4
− 68	− 13	+ 51	+ 84	+ **97**	+ 95	+ 86	+ 81	+ 70	+ 43	+ 23	+ 6	209	53·0
− 24	+ 31	+ 63	+ **81**	+ 75	+ 65	+ 55	+ 46	+ 35	+ 11	0	− 10	143	38·5
− 27	+ 11	+ 33	+ 48	+ **50**	+ 45	+ 44	+ 44	+ 37	+ 25	+ 13	+ 2	96	29·3
− 34	+ 12	+ 44	+ 60	+ **64**	+ 59	+ 55	+ 51	+ 41	+ 22	+ 11	+ 1	123	35·0
− 98	− 29	+ 39	+ 85	+ 108	+ **111**	+ 102	+ 90	+ 72	+ 48	+ 24	+ 4	247	56·9
−137	− 55	+ 25	+ 88	+ 139	+ **162**	+ 152	+ 134	+ 103	+ 70	+ 41	+ 18	345	77·7
− 90	− 24	+ 36	+ 78	+ 104	+ **111**	+ 103	+ 92	+ 72	+ 46	+ 25	+ 8	237	56·2

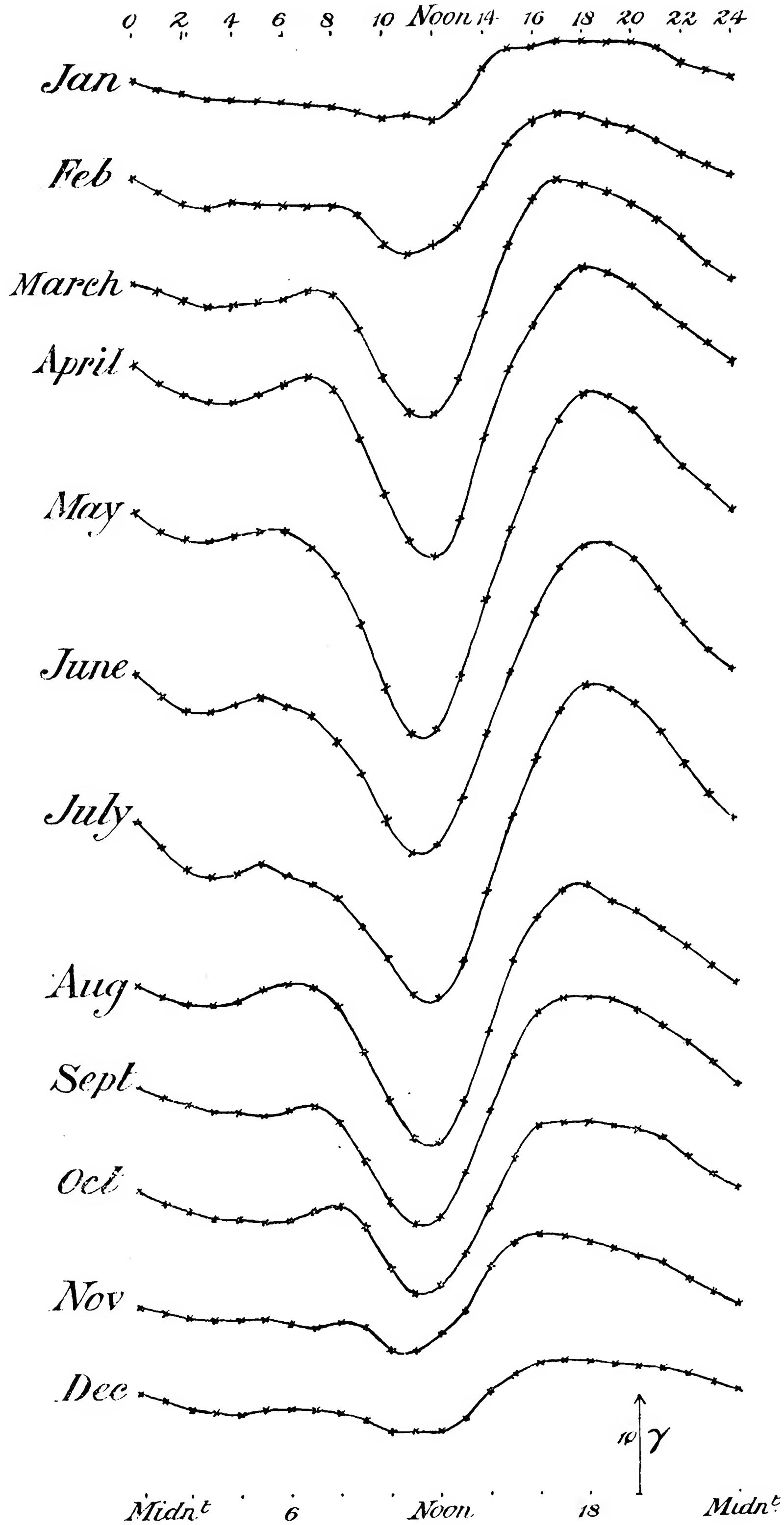

Fig. 3. Vertical force.

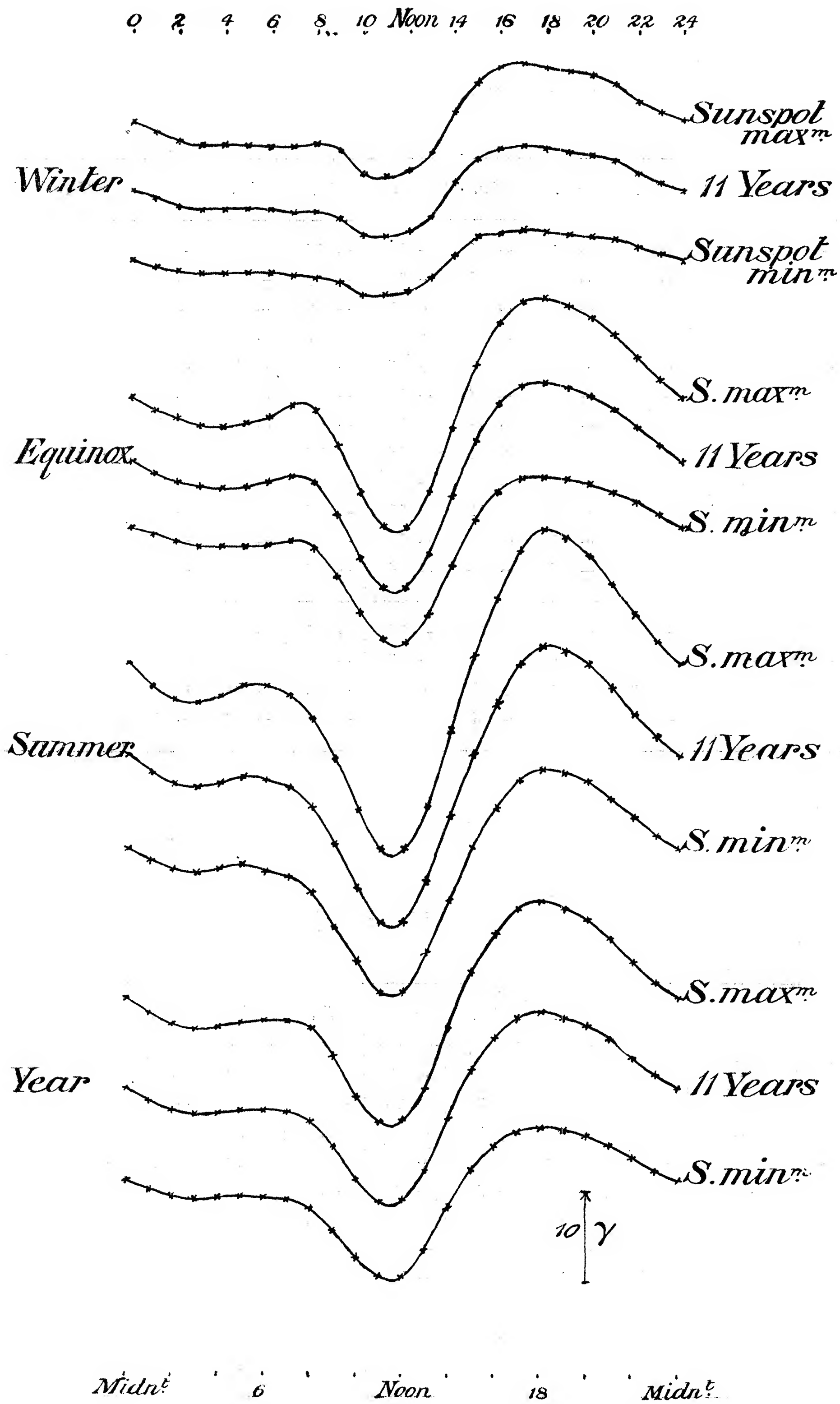

Fig. 4. Vertical force.

TABLE XI.—Diurnal Inequality in Vertical Force,

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
January . .	− 9	− 11	− 14	− 13	− 11	− 13	− 17	− 21	− 26	− **30**	− 25	− 28
February . .	− 8	− 16	− 21	− 18	− 16	− 16	− 17	− 20	− 25	− 43	− **49**	− 46
March . . .	+ 8	− 2	− 6	− 5	− 6	− 8	− 2	− 7	− 35	− 75	−108	−**113**
April . . .	+ 17	+ 7	+ 3	+ 3	+ 2	+ 5	+ 7	− 9	− 50	− 99	−140	−**154**
May	+ 18	+ 10	+ 2	+ 8	+ 9	+ 3	− 12	− 34	− 80	−127	−162	−**165**
June . . .	+ 2	− 10	− 9	− 4	− 4	− 14	− 20	− 39	− 70	−111	−**140**	−131
July	− 7	− 24	− 28	− 24	− 17	− 31	− 32	− 42	− 68	− 92	−**127**	−122
August . . .	+ 3	− 1	− 2	+ 3	+ 15	+ 15	+ 12	− 6	− 48	− 86	−119	−**126**
September. .	0	− 5	− 9	− 8	− 11	− 8	− 3	− 19	− 52	− 86	−**108**	−105
October. . .	− 1	− 7	− 14	− 12	− 12	− 11	− 5	− 2	− 17	− 50	− **74**	− **74**
November. .	− 8	− 9	− 11	− 15	− 13	− 19	− 20	− 21	− 26	− **43**	− 42	− 28
December . .	+ 2	− 3	− 5	− 6	− 4	− 4	− 5	− 9	− 16	− **29**	− 25	− 27
Winter . . .	− 6	− 10	− 13	− 13	− 11	− 13	− 15	− 18	− 23	− **36**	− 35	− 32
Equinox . .	+ 6	− 2	− 7	− 6	− 7	− 5	− 1	− 9	− 39	− 78	−107	−**111**
Summer . .	+ 4	− 6	− 9	− 4	+ 1	− 7	− 13	− 30	− 67	−104	−**137**	−136
Year. . . .	+ 1	− 6	− 9	− 8	− 6	− 8	− 10	− 19	− 43	− 73	− **93**	− **93**

TABLE XII.—Diurnal Inequality in Vertical

Year.	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
1890	0	− 8	− 12	− 8	− 5	− 8	− 8	− 18	− 40	− 68	− 86	− **87**
1891	− 9	− 13	− 19	− 19	− 14	− 13	− 14	− 23	− 51	− 88	−**112**	−110
1892	− 16	− 25	− 32	− 28	− 21	− 21	− 22	− 32	− 57	− 95	−**123**	−122
1893	− 4	− 15	− 17	− 13	− 7	− 6	− 4	− 14	− 47	− 99	−**132**	−131
1894	− 8	− 19	− 27	− 28	− 25	− 22	− 21	− 28	− 60	−103	−**130**	−125
1895	− 9	− 21	− 26	− 25	− 22	− 20	− 20	− 27	− 56	− 97	−**119**	−118
1896	− 5	− 16	− 20	− 22	− 18	− 17	− 19	− 29	− 59	− 95	−**118**	−114
1897	+ 5	− 7	− 14	− 15	− 15	− 17	− 20	− 29	− 54	− 87	−**110**	−106
1898	− 3	− 12	− 17	− 14	− 12	− 15	− 19	− 32	− 58	− 90	−**110**	−107
1899	− 7	− 14	− 16	− 14	− 12	− 12	− 14	− 23	− 48	− 75	− **95**	− 94
1900	+ 11	+ 3	− 2	− 1	+ 1	− 5	− 7	− 16	− 40	− 73	− 99	−**100**

from Sunspot Minimum Years. (Unit 0·1γ.)

13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.	Range.	A.D.
− 12	+ 10	+ 32	+ 25	+ **33**	+ 29	+ 28	+ 30	+ 24	+ 14	+ 8	− 1	63	19·3
− 38	− 6	+ 30	+ 44	+ **49**	+ **49**	+ 43	+ 42	+ 35	+ 23	+ 18	+ 9	98	28·4
− 87	− 32	+ 26	+ 62	+ **75**	+ 68	+ 63	+ 58	+ 50	+ 39	+ 24	+ 11	188	40·4
−122	− 53	+ 3	+ 38	+ 75	+ **92**	+ 89	+ 81	+ 70	+ 57	+ 45	+ 31	246	52·2
−115	− 49	+ 9	+ 61	+ 94	+**108**	+107	+ 98	+ 81	+ 58	+ 45	+ 33	273	62·0
− 88	− 32	+ 10	+ 60	+ 93	+108	+**109**	+102	+ 79	+ 57	+ 35	+ 19	249	56·1
− 88	− 33	+ 28	+ 71	+105	+**121**	+117	+104	+ 83	+ 58	+ 33	+ 13	248	61·2
− 90	− 32	+ 27	+ 57	+ 76	+ **79**	+ 67	+ 58	+ 46	+ 30	+ 15	+ 5	205	42·4
− 64	− 8	+ 34	+ 64	+ **71**	+ 64	+ 66	+ 61	+ 52	+ 41	+ 28	+ 8	179	40·6
− 50	− 13	+ 26	+ **47**	+ 45	+ 46	+ 45	+ 43	+ 40	+ 28	+ 17	+ 7	121	28·6
− 5	+ 26	+ **42**	+ 39	+ 38	+ 35	+ 30	+ 23	+ 23	+ 9	0	− 9	85	22·2
− 14	0	+ 9	+ 16	+ **20**	+ **20**	+ 18	+ 15	+ 17	+ 15	+ 9	+ 5	49	12·2
− 17	+ 7	+ 28	+ 31	+ **35**	+ 33	+ 30	+ 28	+ 25	+ 15	+ 9	+ 1	71	20·2
− 81	− 27	+ 22	+ 53	+ 67	+ **68**	+ 66	+ 61	+ 53	+ 41	+ 29	+ 14	179	40·0
− 95	− 37	+ 19	+ 62	+ 92	+**104**	+100	+ 91	+ 72	+ 51	+ 32	+ 17	241	53·8
− 64	− 18	+ 23	+ 49	+ 64	+ **68**	+ 65	+ 60	+ 50	+ 36	+ 23	+ 11	161	37·5

Force, from Individual Years. (Unit 0·1γ.)

13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.	Range.	A.D.
− 61	− 15	+ 23	+ 47	+ 61	+ **65**	+ 62	+ 56	+ 46	+ 33	+ 22	+ 9	152	35·3
− 78	− 18	+ 30	+ 70	+ 89	+ **99**	+ 93	+ 79	+ 60	+ 38	+ 20	+ 4	211	48·5
− 84	− 19	+ 40	+ 80	+104	+**115**	+108	+ 97	+ 76	+ 50	+ 25	+ 2	238	58·1
−101	− 35	+ 31	+ 72	+ 99	+**102**	+ 94	+ 82	+ 66	+ 44	+ 25	+ 10	234	52·1
− 91	− 25	+ 33	+ 81	+109	+**117**	+108	+ 98	+ 76	+ 50	+ 30	+ 12	247	59·4
− 82	− 15	+ 39	+ 77	+103	+**109**	+103	+ 89	+ 69	+ 42	+ 21	+ 5	228	54·7
− 82	− 21	+ 33	+ 70	+ 91	+ **97**	+ 93	+ 86	+ 71	+ 50	+ 31	+ 13	215	52·9
− 77	− 28	+ 21	+ 54	+ 76	+ **87**	+ 84	+ 79	+ 68	+ 53	+ 33	+ 19	197	48·3
− 71	− 17	+ 30	+ 63	+ 82	+ **91**	+ 85	+ 77	+ 63	+ 45	+ 27	+ 12	201	48·0
− 63	− 17	+ 28	+ 55	+ 73	+ **79**	+ 77	+ 69	+ 56	+ 39	+ 21	+ 6	174	42·0
− 70	− 23	+ 18	+ 44	+ 59	+ **61**	+ 57	+ 53	+ 48	+ 36	+ 27	+ 18	161	36·3

TABLE XIII.—Diurnal Inequality in Total

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
January	− 4	− 7	− 8	− 3	+ 4	+ 8	+ 4	− 8	− 34	− 57	− **65**	− 63
February	− 1	− 13	− 16	− 6	0	+ 4	+ 5	− 5	− 37	− 86	−**108**	− 92
March	+ 12	+ 3	− 2	− 1	+ 7	+ 10	+ 11	− 15	− 82	−153	−**195**	−176
April	+ 32	+ 14	+ 6	+ 4	+ 10	+ 17	+ 8	− 34	−115	−198	−**245**	−232
May	+ 29	+ 18	+ 12	+ 12	+ 10	− 6	− 46	− 95	−160	−228	−**261**	−234
June	+ 15	− 3	− 6	− 2	− 5	− 33	− 67	−117	−168	−217	−**235**	−204
July	+ 19	− 7	− 18	− 18	− 19	− 48	− 79	−118	−169	−207	−**231**	−207
August	+ 29	+ 15	+ 13	+ 8	+ 9	− 1	− 32	− 82	−149	−200	−**218**	−188
September	+ 28	+ 17	+ 9	+ 7	+ 2	− 4	− 23	− 71	−139	−193	−**204**	−164
October	+ 16	+ 10	+ 3	+ 6	+ 9	+ 8	+ 5	− 19	− 79	−146	−**172**	−146
November	− 7	− 10	− 8	− 3	+ 5	+ 4	− 4	− 13	− 47	− 90	− **97**	− 70
December	− 4	− 10	− 7	− 3	+ 9	+ 16	+ 14	+ 4	− 19	− 49	− 56	− **57**
Year (11 years)	+ 14	+ 2	− 2	0	+ 3	− 2	− 17	− 48	−100	−152	−**174**	−153
Sunspot maximum	+ 15	+ 2	− 4	− 2	+ 2	− 2	− 20	− 55	−116	−179	−**205**	−181
Sunspot minimum	+ 13	+ 4	+ 1	+ 4	+ 7	+ 1	− 12	− 37	− 81	−123	−**139**	−121

TABLE XIV.—Diurnal Inequality

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
	′	′	′	′	′	′	′	′	′	′	′	′
January	−0·04	−0·07	−0·17	−0·28	−0·43	−**0·52**	−0·51	−0·33	+0·03	+0·32	+**0·51**	+0·36
February	−0·14	−0·15	−0·17	−0·25	−0·39	−0·51	−**0·52**	−0·34	+0·05	+0·35	+**0·55**	+0·45
March	−0·32	−0·33	−0·36	−0·36	−0·43	−**0·46**	−0·31	+0·08	+0·61	+0·96	+**1·01**	+0·67
April	−0·48	−0·40	−0·37	−0·36	−0·33	−0·26	+0·04	+0·51	+1·05	+**1·46**	+1·39	+0·89
May	−0·38	−0·31	−0·25	−0·17	−0·03	+0·22	+0·62	+1·00	+**1·19**	+1·16	+0·89	+0·49
June	−0·36	−0·31	−0·28	−0·23	−0·06	+0·27	+0·70	+1·07	+1·34	+**1·35**	+1·05	+0·65
July	−0·38	−0·35	−0·31	−0·25	−0·07	+0·20	+0·60	+1·02	+1·33	+**1·43**	+1·17	+0·69
August	−0·55	−0·44	−0·41	−0·30	−0·09	+0·18	+0·64	+1·19	+**1·49**	+1·48	+1·11	+0·51
September	−0·53	−0·47	−0·45	−0·46	−0·43	−0·22	+0·18	+0·70	+1·17	+**1·36**	+1·16	+0·56
October	−0·44	−0·44	−0·49	−0·56	−**0·65**	−0·60	−0·37	+0·15	+0·78	+**1·18**	+1·15	+0·86
November	−0·16	−0·20	−0·29	−0·38	−0·50	−**0·58**	−0·52	−0·25	+0·23	+0·55	+**0·67**	+0·53
December	+0·01	−0·05	−0·16	−0·27	−0·41	−**0·51**	−0·48	−0·37	−0·10	+0·17	+**0·33**	+0·32
Year (11 years)	−0·31	−0·29	−0·31	−0·32	−0·32	−0·23	+0·01	+0·37	+0·76	+**0·98**	+0·92	+0·58
Sunspot maximum	−0·43	−0·40	−0·42	−0·43	−0·39	−0·29	+0·03	+0·49	+0·98	+**1·25**	+1·20	+0·82
Sunspot minimum	−0·21	−0·18	−0·19	−0·22	−**0·24**	−0·17	+0·01	+0·29	+0·60	+**0·76**	+0·66	+0·36

Force, from 11 years. (Unit 0·1γ.)

13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.	Range.	A.D.
− 32	+ 10	+ 28	+ 25	+ 32	+ 36	**+ 37**	+ 37	+ 31	+ 17	+ 10	+ 2	102	23·4
− 62	− 14	+ 29	+ 50	+ 59	**+ 61**	+ 56	+ 57	+ 47	+ 34	+ 24	+ 14	169	36·7
−119	− 40	+ 37	+ 86	+104	**+105**	+103	+ 95	+ 82	+ 65	+ 41	+ 22	300	65·2
−170	− 65	+ 19	+ 74	+121	**+147**	+145	+132	+111	+ 91	+ 73	+ 55	392	88·3
−163	− 69	+ 18	+ 90	+153	+190	**+191**	+170	+137	+103	+ 79	+ 53	452	105·3
−137	− 48	+ 33	+104	+162	+193	**+201**	+182	+143	+100	+ 66	+ 43	436	103·5
−146	− 52	+ 43	+111	+168	**+202**	**+202**	+186	+150	+112	+ 76	+ 48	433	109·8
−121	− 35	+ 44	+ 91	+124	**+140**	+134	+126	+107	+ 84	+ 60	+ 42	358	85·5
− 94	− 20	+ 38	+ 82	+100	+111	**+120**	+113	+ 98	+ 83	+ 65	+ 40	324	76·0
− 92	− 30	+ 28	+ 61	+ 73	+ 82	+ 82	**+ 83**	+ 78	+ 62	+ 46	+ 32	255	57·0
− 38	+ 11	+ 39	+ 53	**+ 58**	+ 55	+ 51	+ 44	+ 38	+ 21	+ 9	− 1	155	32·3
− 37	− 7	+ 11	+ 24	+ 30	**+ 31**	+ 28	+ 25	+ 24	+ 18	+ 12	+ 4	88	20·8
−101	− 30	+ 31	+ 71	+ 99	**+113**	+112	+104	+ 87	+ 66	+ 47	+ 30	287	66·6
−124	− 38	+ 35	+ 87	+122	**+138**	+136	+125	+103	+ 75	+ 53	+ 33	343	77·2
− 76	− 19	+ 27	+ 54	+ 72	+ 82	**+ 83**	+ 78	+ 67	+ 52	+ 38	+ 25	222	50·7

in Inclination, from 11 Years.

13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.	Range.	A.D.
′	′	′	′	′	′	′	′	′	′	′	′	′	′
+0·13	+0·07	+0·14	+0·20	+0·19	+0·11	+0·07	+0·08	+0·09	+0·04	+0·02	0·00	1·03	0·196
+0·27	+0·17	+0·21	+0·27	+0·26	+0·18	+0·09	−0·01	−0·05	−0·09	−0·12	−0·12	1·07	0·238
+0·32	+0·13	+0·07	+0·09	+0·13	+0·02	−0·11	−0·18	−0·24	−0·30	−0·35	−0·35	1·47	0·341
+0·47	+0·17	−0·02	−0·17	−0·29	−0·38	−0·44	−0·47	−0·47	−0·49	−0·51	**−0·53**	1·99	0·498
+0·24	+0·04	−0·14	−0·31	−0·50	−0·63	**−0·71**	−0·61	−0·53	−0·47	−0·44	−0·40	1·90	0·489
+0·33	+0·02	−0·26	−0·39	−0·56	−0·71	**−0·83**	−0·77	−0·64	−0·54	−0·45	−0·39	2·18	0·565
+0·27	−0·05	−0·29	−0·41	−0·51	−0·61	**−0·72**	−0·71	−0·62	−0·53	−0·48	−0·41	2·15	0·559
+0·09	−0·11	−0·18	−0·19	−0·25	−0·44	−0·66	**−0·69**	−0·67	−0·62	−0·57	−0·56	2·18	0·559
+0·17	+0·05	+0·07	+0·10	+0·03	−0·17	−0·34	−0·42	−0·45	−0·50	**−0·57**	−0·55	1·93	0·463
+0·53	+0·31	+0·23	+0·23	+0·09	−0·07	−0·17	−0·22	−0·28	−0·37	−0·43	−0·44	1·83	0·460
+0·37	+0·35	+0·32	+0·22	+0·08	+0·02	−0·01	−0·04	−0·04	−0·09	−0·11	−0·15	1·25	0·278
+0·23	+0·21	+0·21	+0·19	+0·13	+0·11	+0·09	+0·11	+0·10	+0·08	+0·04	+0·03	0·84	0·196
+0·28	+0·11	+0·03	−0·01	−0·10	−0·21	−0·31	**−0·33**	−0·32	−0·32	**−0·33**	−0·32	1·31	0·336
+0·46	+0·21	+0·06	−0·04	−0·16	−0·31	−0·42	−0·44	−0·44	**−0·45**	**−0·45**	−0·43	1·70	0·458
+0·11	0·00	−0·03	−0·02	−0·05	−0·15	−0·22	−0·22	−0·22	−0·22	−0·23	−0·23	1·00	0·233

TABLE XV.—Diurnal Inequality in

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
	′	′	′	′	′	′	′	′	′	′	′	′
1890	**−0·23**	−0·19	−0·19	−0·22	**−0·23**	−0·15	+0·04	+0·30	+0·62	**+0·76**	+0·65	+0·32
1891	−0·30	−0·28	−0·30	**−0·34**	−0·33	−0·20	+0·03	+0·38	+0·76	**+0·97**	+0·91	+0·59
1892	−0·45	−0·41	−0·41	−0·40	−0·32	−0·23	+0·06	+0·51	+1·00	**+1·29**	+1·20	+0·77
1893	−0·44	−0·41	−0·41	−0·43	−0·43	−0·29	+0·05	+0·54	+1·06	**+1·35**	+1·31	+0·88
1894	−0·42	−0·39	−0·44	−0·45	−0·43	−0·33	0·00	+0·47	+0·96	**+1·25**	+1·20	+0·90
1895	−0·39	−0·40	−0·40	**−0·42**	−0·40	−0·30	+0·01	+0·43	+0·89	**+1·10**	+1·09	+0·72
1896	−0·31	−0·28	−0·30	−0·30	**−0·32**	−0·24	−0·03	+0·29	+0·70	**+0·94**	+0·90	+0·58
1897	−0·26	−0·24	−0·26	−0·29	**−0·30**	−0·26	−0·08	+0·25	+0·58	**+0·82**	+0·75	+0·46
1898	−0·26	−0·25	−0·25	**−0·27**	**−0·27**	−0·18	+0·01	+0·32	+0·62	**+0·76**	+0·69	+0·40
1899	−0·26	−0·23	−0·22	−0·24	−0·27	−0·21	−0·01	+0·30	+0·65	**+0·82**	+0·71	+0·42
1900	−0·15	−0·15	−0·17	−0·20	−0·20	−0·16	0·00	+0·26	+0·55	**+0·71**	+0·63	+0·33

TABLE XVI.—Diurnal Inequality in North

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
January . .	+ 22	+ 23	+ 31	+ 45	+ 66	**+ 78**	+ 76	+ 51	− 6	− 66	**−112**	−111
February . .	+ 44	+ 36	+ 36	+ 48	+ 67	+ 83	**+ 84**	+ 59	− 2	− 74	−135	**−141**
March . . .	+ 72	+ 68	+ 70	+ 70	+ 83	**+ 89**	+ 78	+ 33	− 60	−158	**−227**	−222
April . . .	+ 93	+ 77	+ 73	+ 75	+ 79	+ 82	+ 56	− 8	−114	−231	**−291**	−275
May	+ 79	+ 69	+ 64	+ 62	+ 59	+ 33	− 22	− 91	−158	−220	**−248**	−229
June. . . .	+ 69	+ 60	+ 61	+ 68	+ 64	+ 28	− 32	−100	−171	−228	**−246**	−228
July	+ 74	+ 66	+ 61	+ 64	+ 60	+ 28	− 30	−101	−176	−236	**−257**	−232
August . . .	+104	+ 89	+ 88	+ 79	+ 65	+ 39	− 27	−114	−200	−259	**−267**	−224
September .	+104	+ 95	+ 92	+ 94	+ 90	+ 67	+ 18	− 63	−164	−245	**−272**	−220
October . .	+ 85	+ 81	+ 83	+ 91	**+103**	+ 98	+ 74	+ 13	− 88	−190	**−242**	−230
November . .	+ 38	+ 37	+ 45	+ 58	+ 75	**+ 85**	+ 76	+ 43	− 28	−101	**−144**	−140
December . .	+ 17	+ 16	+ 27	+ 40	+ 61	**+ 76**	+ 72	+ 54	+ 14	− 42	− 82	**− 98**
Winter . . .	+ 30	+ 28	+ 35	+ 48	+ 67	**+ 80**	+ 77	+ 52	− 6	− 71	−118	**−123**
Equinox . .	+ 89	+ 80	+ 79	+ 82	+ 89	+ 84	+ 56	− 6	−106	−206	**−258**	−237
Summer . .	+ 82	+ 71	+ 68	+ 68	+ 62	+ 32	− 28	−102	−176	−236	**−255**	−228
Year (11 years)	+ 67	+ 60	+ 61	+ 66	+ 73	+ 65	+ 35	− 19	− 96	−171	**−210**	−196
Sunspot maximum	+ 86	+ 80	+ 81	+ 86	+ 89	+ 81	+ 41	− 27	−121	−211	**−260**	−245
Sunspot minimum	+ 48	+ 40	+ 41	+ 48	+ 57	+ 51	+ 29	− 12	− 75	−135	**−163**	−149

Inclination, from Individual Years.

13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.	Range.	A.D.
′	′	′	′	′	′	′	′	′	′	′	′	′	′
+0·06	−0·04	−0·05	−0·06	−0·06	−0·14	−0·20	−0·19	−0·19	−0·18	−0·20	**−0·23**	0·99	0·229
+0·27	+0·08	−0·04	−0·04	−0·14	−0·23	−0·28	−0·29	−0·28	−0·30	−0·32	−0·32	1·31	0·333
+0·44	+0·19	+0·04	−0·07	−0·19	−0·32	−0·42	−0·43	−0·45	−0·46	**−0·47**	**−0·47**	1·76	0·458
+0·45	+0·16	−0·01	−0·11	−0·20	−0·33	−0·44	**−0·47**	−0·45	−0·46	−0·46	−0·46	1·82	0·483
+0·52	+0·28	+0·12	−0·01	−0·16	−0·35	−0·46	**−0·48**	−0·47	−0·46	−0·44	−0·41	1·73	0·475
+0·42	+0·23	+0·10	+0·01	−0·08	−0·24	−0·36	−0·39	−0·40	**−0·42**	**−0·42**	−0·39	1·52	0·417
+0·29	+0·14	+0·05	+0·01	−0·07	−0·19	−0·29	**−0·32**	−0·30	−0·31	−0·31	**−0·32**	1·26	0·325
+0·23	+0·14	+0·10	+0·07	−0·05	−0·17	−0·27	−0·27	−0·23	−0·23	−0·26	−0·23	1·12	0·283
+0·18	+0·07	+0·06	+0·06	−0·03	−0·11	−0·24	−0·26	−0·26	−0·26	**−0·27**	**−0·27**	1·03	0·265
+0·19	+0·06	+0·03	+0·03	−0·04	−0·14	−0·22	−0·24	−0·25	−0·28	**−0·31**	−0·30	1·13	0·268
+0·08	−0·04	−0·06	−0·04	−0·05	−0·15	**−0·23**	**−0·23**	−0·20	−0·19	−0·18	−0·16	0·94	0·213

Component, from 11 Years. (Unit 0·1γ.)

13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.	Range.	A.D.
−79	−47	−34	−35	−24	−5	+9	+18	+22	+27	+27	+25	190	43·3
−119	−89	−63	−43	−27	−8	+10	+31	+45	+51	+55	+52	225	58·4
−179	−123	−64	−20	+6	+32	+56	+69	+79	+85	+84	+79	316	87·8
−226	−146	−66	−1	+55	+95	+112	**+116**	+114	+114	+110	+107	407	113·2
−187	−123	−48	+22	+90	+137	**+158**	+143	+124	+108	+97	+87	406	110·8
−183	−115	−37	+26	+91	+139	**+168**	+159	+132	+107	+89	+79	414	111·7
−181	−109	−29	+35	+92	+134	**+156**	+153	+133	+112	+97	+83	413	112·5
−163	−97	−34	+16	+62	+105	+133	**+137**	+132	+121	+110	+106	404	115·5
−157	−101	−56	−15	+22	+60	+91	+106	+109	+114	**+120**	+111	392	107·7
−183	−124	−73	−36	0	+34	+57	+73	+86	+96	+99	+93	345	97·2
−116	−87	−58	−31	−2	+13	+25	+35	+42	+46	+45	+44	229	58·9
−86	−67	−50	−34	−15	−4	+6	+10	+18	+22	+24	+22	174	39·9
−100	−73	−51	−36	−17	−1	+13	+23	+32	+37	+38	+36	203	49·7
−186	−123	−65	−18	+21	+55	+79	+91	+97	+102	**+103**	+98	361	100·4
−179	−111	−37	+25	+84	+129	**+154**	+148	+130	+112	+98	+89	409	112·7
−155	−102	−51	−10	+29	+61	+82	**+87**	+86	+84	+80	+74	297	84·2
−198	−134	−67	−11	+38	+78	+102	**+109**	+108	+104	+99	+93	369	106·2
−111	−69	−30	−2	+21	+45	+61	**+64**	**+64**	+62	+60	+55	227	62·2

TABLE XVII.—Diurnal Inequality in West

	1h.	2h.	3h.	4h.	5h.	6h.	7h.	8h.	9h.	10h.	11h.	12h.
January	− 62	− 49	− 35	− 28	− 20	− 15	− 18	− 32	− 37	0	+ 55	+120
February	− 83	− 70	− 63	− 55	− 48	− 42	− 38	− 52	− 66	− 26	+ 57	+141
March	− 75	− 73	− 73	− 74	− 72	− 72	−102	−158	**−173**	−102	+ 42	+197
April	− 50	− 58	− 68	− 84	− 98	−127	−186	**−238**	−232	−140	+ 23	+204
May	− 52	− 67	− 84	−113	−163	−211	**−256**	−251	−208	− 84	+ 76	+221
June	− 47	− 64	− 86	−124	−187	−248	−284	**−288**	−242	−126	+ 35	+186
July	− 48	− 70	− 89	−121	−186	−238	−263	**−265**	−226	−124	+ 26	+182
August	− 60	− 76	− 91	−114	−158	−204	−243	**−249**	−190	− 62	+100	+257
September	− 72	− 78	− 88	− 96	−103	−127	−165	**−190**	−154	− 43	+108	+252
October	− 64	− 58	− 52	− 44	− 41	− 46	− 73	−130	**−154**	− 86	+ 61	+184
November	− 61	− 44	− 31	− 25	− 21	− 21	− 24	− 49	− 71	− 31	+ 53	+134
December	− 60	− 44	− 28	− 14	− 7	− 2	− 5	− 13	− 26	− 2	+ 48	+104
Winter	− 67	− 52	− 39	− 31	− 24	− 20	− 21	− 37	− 50	− 15	+ 53	+125
Equinox	− 65	− 67	− 70	− 75	− 79	− 93	−132	**−179**	−178	− 93	+ 59	+209
Summer	− 52	− 69	− 88	−118	−174	−225	−262	**−263**	−217	− 99	+ 59	+212
Year (11 years)	− 61	− 63	− 66	− 74	− 92	−113	−138	**−160**	−148	− 69	+ 57	+182
Sunspot maximum	− 76	− 81	− 85	− 94	−114	−138	−167	**−193**	−181	− 90	+ 54	+201
Sunspot minimum	− 45	− 44	− 47	− 57	− 73	− 91	−114	**−133**	−121	− 51	+ 58	+164

Component, from 11 Years. (Unit 0·1γ.)

13h.	14h.	15h.	16h.	17h.	18h.	19h.	20h.	21h.	22h.	23h.	24h.	Range.	A.D.
+157	+134	+ 87	+ 58	+ 37	+ 15	− 13	− 43	− 70	− **84**	− 83	− 75	241	55·3
+190	**+195**	+148	+ 88	+ 54	+ 28	+ 1	− 27	− 60	− 81	− 92	− **94**	289	75·0
+282	**+288**	+226	+134	+ 57	+ 23	− 2	− 21	− 45	− 60	− 67	− 76	461	103·9
+305	**+311**	+246	+170	+101	+ 47	+ 16	− 3	− 18	− 35	− 41	− 45	549	118·6
+287	**+288**	+239	+178	+125	+ 77	+ 46	+ 23	+ 6	− 9	− 23	− 37	544	130·2
+267	**+299**	+275	+220	+156	+109	+ 75	+ 55	+ 32	+ 16	− 6	− 27	587	143·9
+274	**+303**	+272	+207	+142	+ 94	+ 69	+ 53	+ 34	+ 14	− 9	− 29	568	139·1
+328	+315	+244	+147	+ 70	+ 34	+ 29	+ 18	+ 4	− 17	− 33	− 48	577	128·8
+309	+277	+195	+108	+ 48	+ 23	+ 8	− 13	− 31	− 44	− 57	− 68	499	110·7
+240	+226	+171	+ 97	+ 53	+ 26	− 3	− 33	− 58	− 71	− 75	− 70	394	88·2
+165	+144	+101	+ 72	+ 46	+ 19	− 8	− 39	− 69	− 82	− **84**	− 77	249	61·3
+133	+115	+ 83	+ 58	+ 33	+ 6	− 22	− 48	− 71	− **82**	− 81	− 77	215	48·4
+161	+147	+105	+ 69	+ 43	+ 17	− 10	− 39	− 67	− 82	− **85**	− 81	246	60·0
+284	+276	+210	+127	+ 65	+ 30	+ 5	− 18	− 38	− 53	− 60	− 65	463	105·4
+289	**+301**	+258	+188	+123	+ 78	+ 55	+ 37	+ 19	+ 1	− 18	− 35	564	135·0
+245	+241	+191	+128	+ 77	+ 42	+ 16	− 7	− 29	− 45	− 54	− 60	405	98·2
+280	**+288**	+236	+167	+103	+ 60	+ 29	− 1	− 25	− 44	− 59	− 70	481	118·2
+213	+198	+144	+ 88	+ 46	+ 24	+ 8	− 10	− 27	− 39	− 45	− 46	346	78·6

As fig. 2 shows, the difference between sunspot maximum and minimum is mainly a matter of amplitude; but in winter, in particular, the tendency in the afternoon curves to a plateau—*i.e.*, the maintenance of a uniform value—is especially characteristic of sunspot minimum. Active regular changes in H at midwinter are mainly confined to the hours 2 a.m. to 2 p.m. Whether we consider the range or the A.D., December and January are clearly the months in which the diurnal inequality is least. In the case of the eleven years and the sunspot maximum group of years, the minimum is in December, but in the S minimum group it falls in January. The differences, however, between the two months are not so decisive as to justify the conclusion that what is true of this particular eleven years is invariably true. The sunspot minimum group in particular, it should be remembered, contained only three years. The maximum amplitude appears in June and July; but May and August are not far behind, especially in the sunspot minimum group of years. In sunspot maximum years April closely resembles May as regards range and A.D., but it exhibits a decided tendency to the evening plateau and morning minimum characteristic of winter. In sunspot minimum years April falls slightly behind September as regards amplitude, while September in all years falls markedly short of August and exhibits a distinct trace of the winter characteristics. These features, in conjunction with the desirability of having the same number of months in each season, seem to justify the division of months adopted. Any grouping which combined February with March, or October with November, seems less appropriate.

One or two features in Table VIII. call for remark. Whether we take the range or the A.D., the amplitude of the mean diurnal inequality for the year was greatest in 1893, the year of largest sunspot frequency, and least in 1890 and 1900, the years of least sunspot frequency. As will be seen presently, the inequality range and the sunspot frequency show a very close parallelism in their variation. The changes in the type of the inequality from year to year are small, and their elucidation requires a more sensitive method, such as the analysis into Fourier waves presently discussed. A tendency can, however, be recognised for the hour of the forenoon minimum to be slightly earlier when sunspots are few than when they are numerous.

§ 8. The V inequality data for the 12 months in Table IX. are shown graphically in fig. 3, while fig. 4 contrasts the diurnal inequalities for the seasons and the year derived from the whole eleven years and from the sunspot maximum and minimum groups of years, as given in Tables IX., X., and XI. The V inequality data are not quite so smooth as those for H, especially in winter. The fact that the H curves were smoothed, while the V curves were not, presumably partly accounts for this. The variation in the type of the inequality throughout the year is less in V than in H. In some months two distinct maxima and minima are visible in V, but the principal maximum always occurs in the afternoon between 4 p.m. and 7 p.m., while the principal minimum, in the forenoon, is as uniform in its time of incidence as the corresponding minimum in H. The time intervening between the morning minimum

and afternoon maximum is less for V than for H, and, speaking generally, the preponderance in changes by day over those by night is greater in V. A further notable difference is that the season in which the double maximum and minimum are most in evidence is summer for V, but winter for H. Also the secondary maximum in the forenoon is in V most prominent at sunspot maximum, while in H it is most prominent at sunspot minimum. In winter the changes during the night hours are exceedingly slow in V as in H; but while the fall to the forenoon minimum is the conspicuous feature in H, it is the rise after the morning minimum that stands out in V. The minimum amplitude occurs as distinctly in December and January for V as for H. In V the lower value is found in December, both in sunspot maximum and minimum, especially the latter, again a difference from what we found in H. The smallness of the amplitude in V in December at sunspot minimum was, however, in considerable measure due to one year, 1890. During the last three months of that year the changes apparent in the V curves, regular and irregular alike, became so small that some defect in the magnetograph was suspected at the time, and the V data in the tables published in the Annual Report of the Kew Committee were confined to the first nine months of the year. There was, however, nothing but the smallness of the movements to suggest instrumental defect, and as the movements rapidly increased in 1891, without anything being done to the instrument, and the scale value determination showed nothing abnormal, the phenomenon was presumably real, and not of instrumental origin. As regards the month when the V inequality is largest, the decision depends upon what we accept as the criterion of amplitude. May comes distinctly first if we take the range, but if we take the A.D. July comes first in the case of the eleven years, and still more so in the case of the sunspot maximum group of years. August falls markedly short of the other summer months, and is inferior even to April.

Table XII. shows that in V, as in H, 1890 and 1900 were the years when the amplitude of the inequality was least; 1893, however, the year of sunspot maximum, was not the year of largest amplitude in V, being exceeded by 1892 and 1894, which were also much more disturbed. The difference in amplitude between years of many and few sunspots is less conspicuous in Table XII. than in Table VIII., and, as will be seen more clearly later, the parallelism between the amplitude of the inequality range and the development of sunspots was not so close in V as in H. Whether this last is a real natural phenomenon, independent of the lesser reliability of the V data in respect especially of temperature correction, is perhaps open to some doubt.

§ 9. If we write the first of equations (2), p. 198, in the form

$$T\,\Delta T = H\,\Delta H + V\,\Delta V,$$

and remember that at Kew $V = 2{\cdot}4H$ roughly, while the range of the diurnal inequality in V is about three-fourths that in H, we see at once that so far as diurnal changes are concerned, the influence of V on T very considerably exceeds that of H.

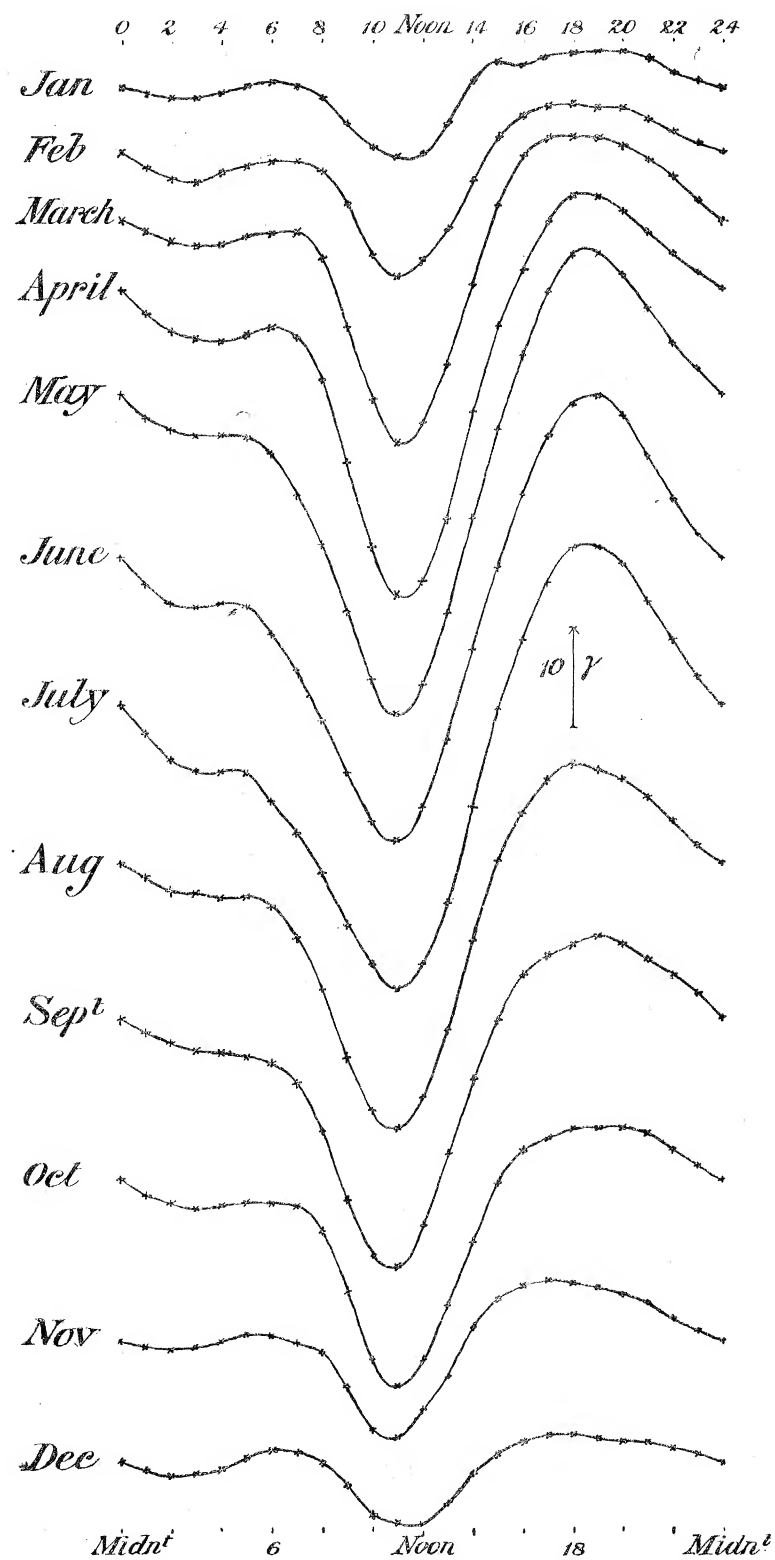

Fig. 5. Total force.

Also the diurnal inequalities in V and H follow a fairly similar course, thus we know *a priori* that the diurnal inequality in T must in general resemble somewhat closely that in V. In winter, however, the amplitude of the V inequality suffers a considerably larger relative reduction than that of H, and the difference of type between the inequalities in the two elements is then at its maximum. Thus we may expect the resemblance of the T to the V inequality to be less close in winter, and the influence of the H inequality to be then more apparent. The accuracy of these anticipations is readily recognised if we compare Table XIII. and fig. 5 with Table IX. and fig. 3.

Owing to the difference in type between the V and H inequalities in December and January, their contributions to the T inequality tend sensibly to neutralise one another. Thus the amplitude of the T inequality at midwinter is markedly less than that of H, while in June and July the amplitudes in the two elements are very similar. Consequently the variation in the range in the course of the year is decidedly more conspicuous in Table XIII. than in Tables V. or IX.

A conspicuous feature in Table XIII. is the uniformity in the time of occurrence of the principal minimum. It is shown at 11 a.m. in every month except December, when the 11 o'clock value just exceeds that for noon. The existence of a second minimum in the early morning is recognisable in most of the monthly curves of fig. 5; there is at least an arrest in the rate of change of the element. The maximum, or principal maximum, always occurs in the afternoon, usually from 6 to 7 p.m. Amongst the curves of fig. 7 are three contrasting the mean diurnal inequality in T for the year in the years of sunspot maximum and minimum and the average year. The variation of type with sunspot frequency makes little appeal to the eye.

§ 10. From the second of formulæ (2) or (3) connecting the I inequality with those for V and H, it appears that the contributions from V and H oppose one another, but that the H contribution must be largely dominant. The phases in the I and H inequalities are opposite, so a comparison of fig. 6, showing the inequalities in I, with fig. 1 does not at first sight show the dominance of H. A little consideration will, however, make this clear, if we remember the difference of phase. Answering to the prominent forenoon minimum in H, we have a prominent forenoon maximum in I, its time of occurrence being visibly earlier in summer than in winter. Again, as in H, there is a distinct difference of type between summer and winter. In summer, the principal or only minimum occurs in the afternoon, just as the principal maximum does in H; whereas in winter the principal minimum, like the principal maximum in H, is found in the morning.

In most months between 2 and 6 p.m. there is at least an arrest in the fall of I, just as there was an arrest in the rise of H. The opposition in phase between the I and T inequalities is readily recognised in fig. 7, where the curves from the two elements representing the mean diurnal variation for the year in the average year and in years of sunspot maximum and minimum are juxtaposed.

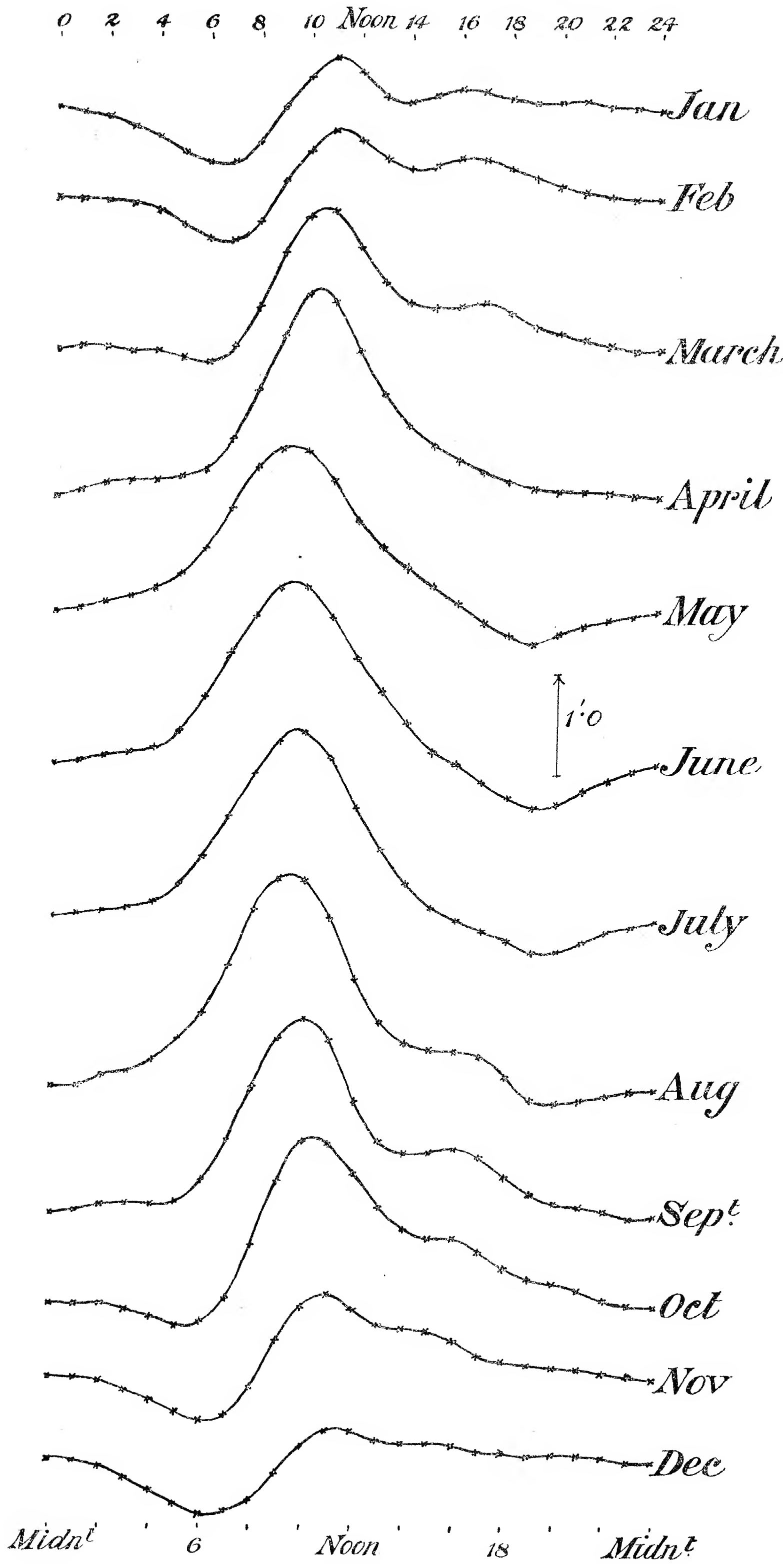

Fig. 6. Inclination.

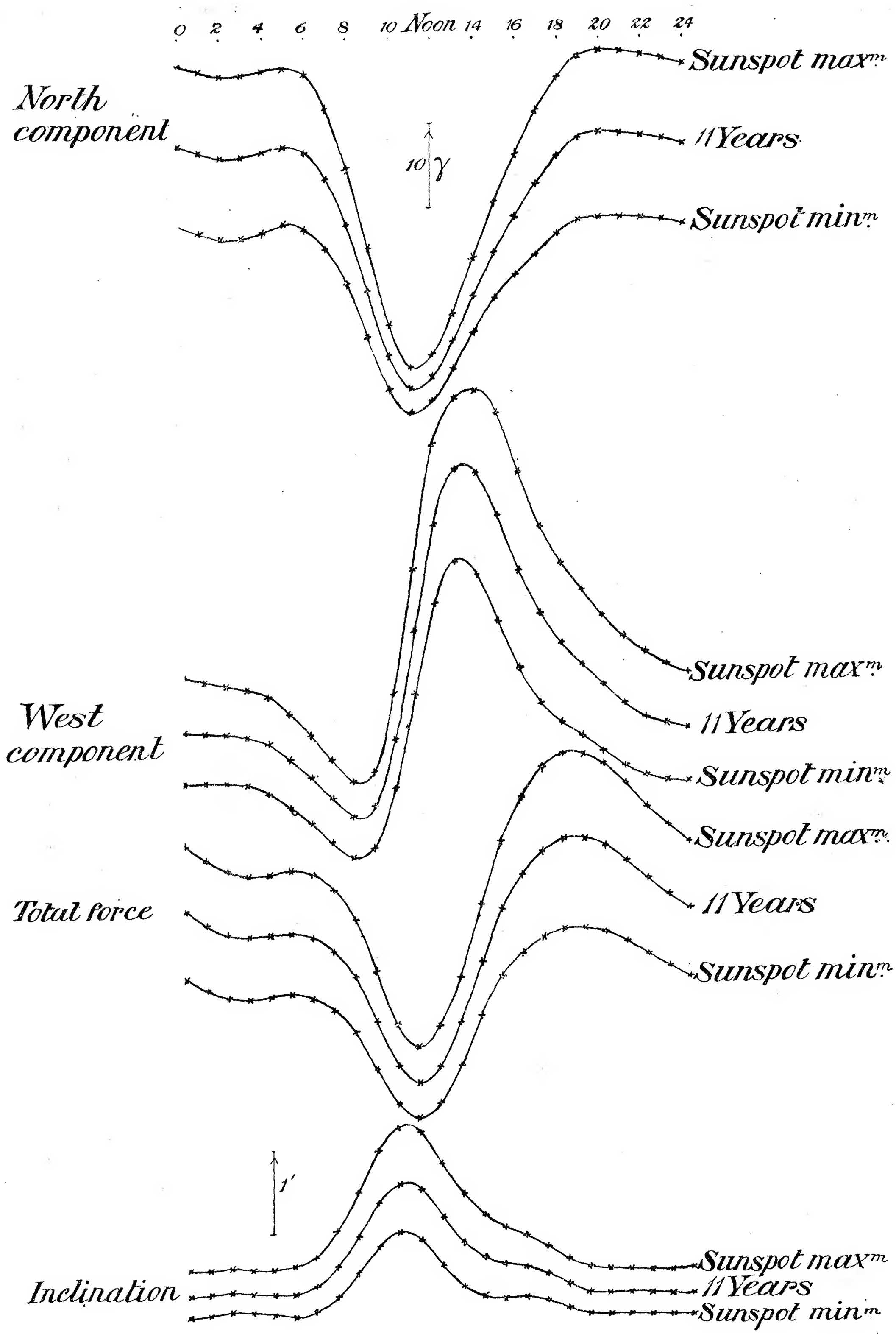

Fig. 7. Mean diurnal inequalities for the year.

The arrest in the afternoon fall of I, it will be seen, is more prominent at sunspot minimum than at sunspot maximum.

According to Table XIV., the December diurnal inequality in I has a decidedly smaller range than the January inequality, but the values of the A.D. for the two months are equal. In this case the August diurnal inequality markedly exceeds that for May, and is practically equal in amplitude to the June and July inequalities. The diminished amplitude of the May inequality in I is associated with the corresponding enhanced amplitude of the inequality in V. So far as amplitude is concerned, one would naturally group May with April, September and October. In amplitude March shows a closer approach to February than to April; in type it stands about equidistant from the two adjacent months.

§ 11. The graphical presentation of N and W diurnal inequalities, as given in Tables XVI. and XVII., is limited to the mean diurnal inequalities for the year from the eleven years and the groups of years of sunspot maximum and minimum. These are shown in the six uppermost curves of fig. 7.

If we take the mean diurnal inequality for the year, the range in H is only about three-fifths that in D, while cos D is three times sin D. It follows from the last of equations (2) that the influence of the D diurnal changes on W will largely exceed that of the H changes. Hence the diurnal inequality in W must show a fairly close approach in type to that in D. In the case of N the H diurnal changes exert more influence than the D changes, but the preponderance is less. As a matter of fact, however, there is a very close resemblance between the diurnal inequalities in H and N. The inequality in D if reversed has a considerable resemblance to that in H, and the contributions from H and D to the N diurnal inequality have opposite signs, so numerically they assist one another.

It is pretty obvious, comparing figs. 1 to 7, that if we measured east-west changes positive to the east, instead of to the west, and I changes positive from instead of towards the vertical, the diurnal inequality curves for the year in all the six elements considered here, and in D as well, would agree in having as one of their most prominent features a principal minimum occurring within an hour or two of noon.

According to Table XVI., the diurnal inequality in N is least in December, January coming next. June and July show the largest ranges, but there is little variation in that respect from April to September. August shows the largest A.D., April coming next. The six months April to September agree in having the maximum or principal maximum in the afternoon, while the other six months have it between 5 and 7 a.m.

Thus the phenomena in N rather favour the sub-division of the year into two seasons, each of six months. In March and October, however, while the forenoon maximum is the larger, it but very slightly exceeds the afternoon maximum, and the grouping of these months with the four midwinter months would be unsatisfactory.

According to Table XVII., December has distinctly the smallest amplitude in the diurnal inequality in W, January coming next. June shows the largest range and A.D., July coming decidedly next so far as A.D. is concerned, though slightly inferior to August as regards range. April closely resembles the midsummer months so far as range is concerned, but fall distinctly short of them in A.D. In this element the most conspicuous difference of type is between the four midwinter months, when the principal minimum occurs between 10 p.m. and midnight, and the other eight months when the principal minimum occurs between 7 and 9 a.m. The maximum, or principal maximum, is the pre-eminent feature. Like the corresponding maximum of westerly declination, it occurs between 1 and 2 p.m. the whole year round.

Comparing Tables XVI. and XVII., we see that the range of the mean diurnal inequality for the year in N is roughly three-fourths that in W; in winter and equinox, however, the fraction is distinctly larger. There is less difference between the values of A.D. in the two elements, especially in equinox.

§ 12. Figs. 8, 9 and 10 give the vector diagrams for the diurnal inequality forces in the horizontal plane. The arms of the cross are oriented in and perpendicular to the geographical meridian. The vector drawn from the centre of the cross, which serves as origin, to the points 1 to 24, represents in magnitude and direction the value at the hour specified of the horizontal component of the force to which the departure of the magnetic field from its mean value for the day may be ascribed. The scale of force is such that each arm of the cross represents 10γ. The vector travels completely round in the general clockwise direction in the course of the 24 hours. The motion is always direct between 6 a.m. and 10 p.m., but in the six months, October to March, there is a reversal of direction during some of the night hours. Details of this reversal are not clearly visible on the scale adopted in fig. 8, so they are shown on a more open scale in fig. 9, which is limited to part of the day.

The monthly diagrams in fig. 8 bring home to the eye the great variability in the type of the regular diurnal variation throughout the year. If the June and December diagrams were alone presented, it would be difficult to believe that they referred to the same physical entity. There are, however, some features common to all the diagrams. The time when the vector is directed due south falls in all cases between 10 and 11 a.m., and so is well in advance of the sun's crossing of the meridian. Again the vector in all cases has its maximum value near 1 p.m. The minimum value is usually seen near 6 p.m., but from April to July it occurs shortly after midnight.

The May, June, and July diagrams closely resemble one another. The August diagram differs from them in having a distinct bay in the afternoon hours, resembling in that respect the September and March diagrams. The diagrams for the midwinter months, November to February, have a pretty close family resemblance. If we take the months in their order, we can recognise a continuous development from January to May, and from July to December; but it is obvious that in some months, especially

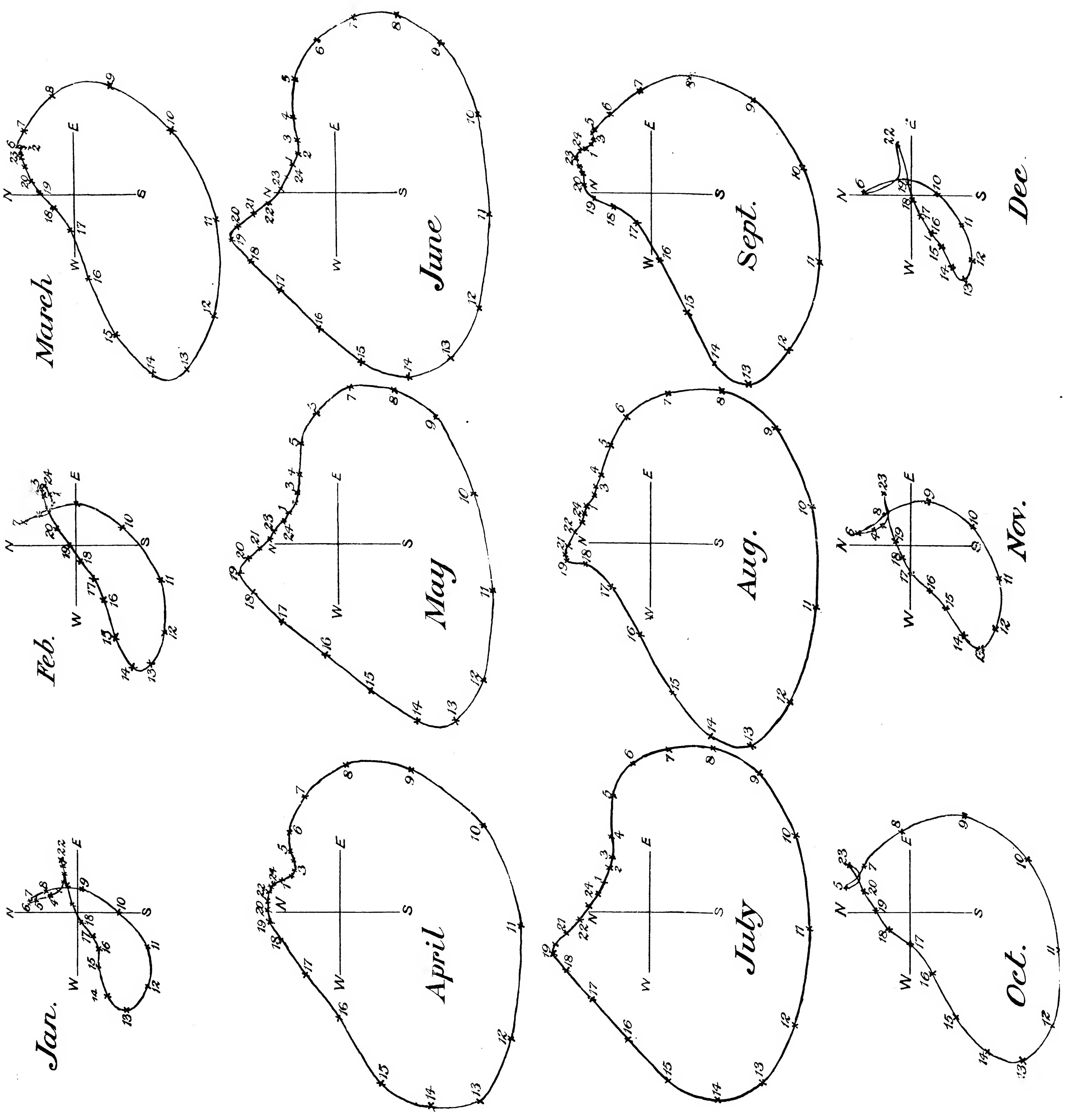

Fig. 8. Vector diagrams in horizontal plane (11 years). Arms of cross each 10γ.

in equinox, the amplitude and type at the beginning and end of the month must differ somewhat largely. The phenomena, for instance, near midnight must be considerably different in the beginning and end of March. What the March diagrams in figs. 8 and 9 show is a blend of different types. We want shorter periods than the calendar month if we are to trace the changes minutely.

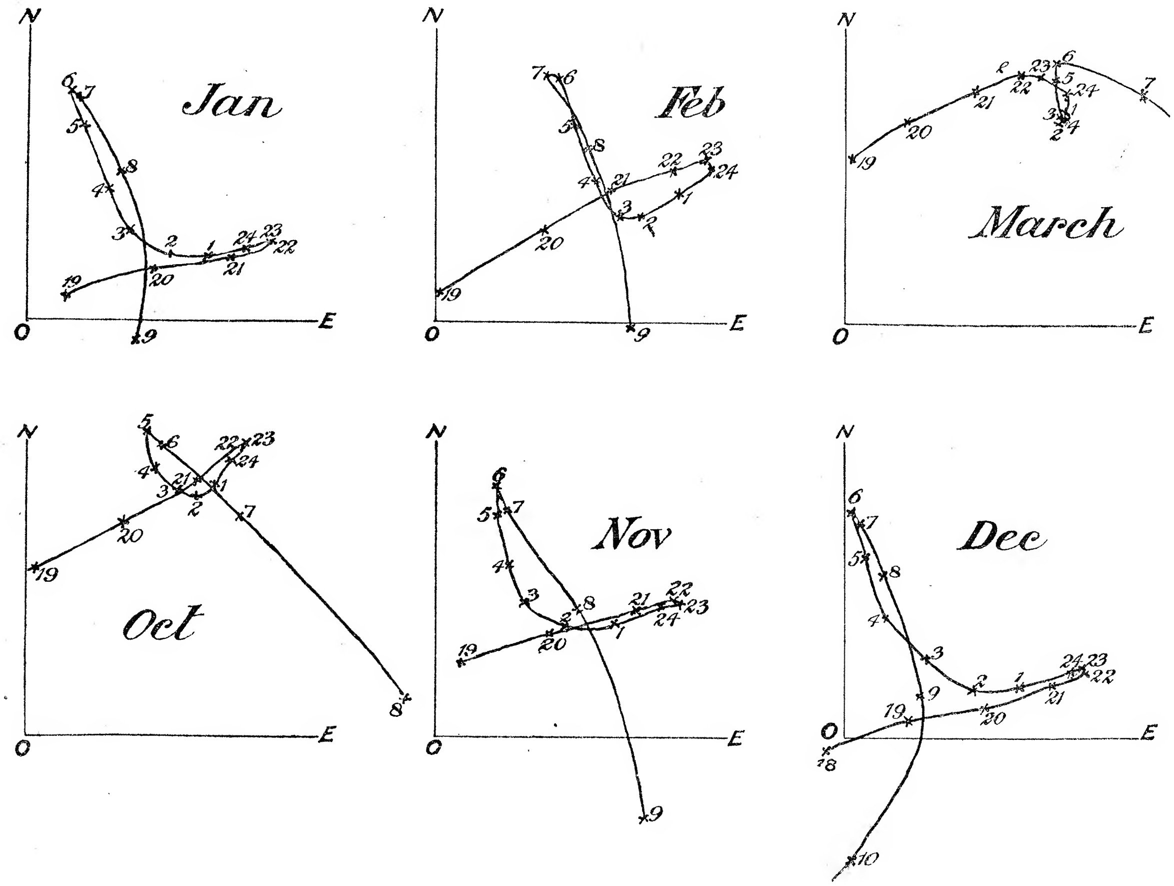

Fig. 9. Vector diagrams in horizontal plane. Details of variation near midnight (24h). (ON = OE $\equiv 10\gamma$.)

Fig. 10 shows the horizontal plane vector diagram for the year in the case of the whole eleven years, as well as in the cases of the sunspot maximum and minimum groups of years. The diagrams for the sunspot maximum and minimum groups of years are drawn from a common origin, as serving best to bring out points of agreement and difference. Except as regards the amplitude of the vector, the most noticeable difference between the sunspot maximum and minimum diagrams is that the indentation extending from about 11 p.m. to 5 a.m. is much more prominent in the latter. This indentation represents an approach to retrograde movement, a characteristic, as we have seen, of the winter season. Also, while a bay is recognisable in the afternoon hours in all three curves, it is deeper in the sunspot minimum diagram than in the other two.

The eye can recognise in fig. 10 that the sunspot minimum vector is in advance of the sunspot maximum vector from 10 a.m. to 10 p.m., the angular difference being considerable in the early afternoon. The vector has, however, its maximum near 1 p.m. in both cases.

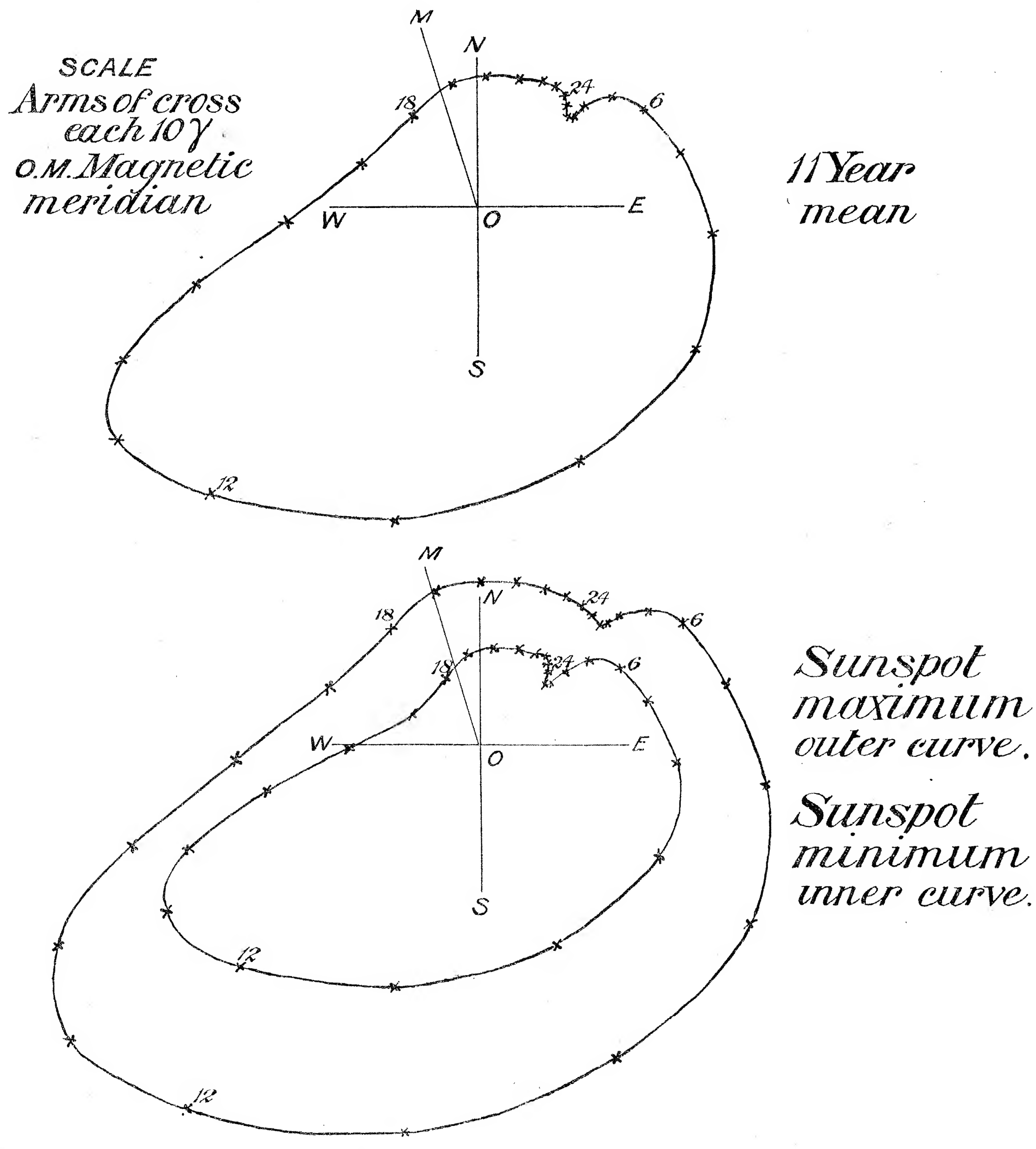

Fig. 10. Vector diagram in horizontal plane. Year.

The year diagram from the eleven years does not show a close resemblance to the diagram of any individual month in fig. 8, a suggestive fact in connection with the significance of mean diurnal inequalities for the whole year. The equinoctial months are those whose diagrams show most resemblance to that for the whole year.

§ 13. Fig. 11 shows vector diagrams in two vertical planes. The upper six curves refer to the vertical plane through the geographical west, the lower six to the vertical plane through geographical north. The upper three WV curves and the upper three NV curves represent the mean diurnal inequalities for the three seasons derived from the whole eleven years. The three lower diagrams in each case represent the mean diurnal inequality for the year, derived respectively from the sunspot minimum group of years, the whole eleven years and the sunspot maximum group of years. The origin of co-ordinates is marked in each case by a small cross. The two large crosses show the orientation, one for the WV diagrams, the other for the NV diagrams ; the arms of these crosses each represent 10γ. It will be noticed that V is measured positively downwards in both cases.

The three WV diagrams for the year differ markedly in amplitude, but comparatively little in type, closely resembling the equinoctial diagram from the eleven years. The special feature is the beak occurring about 8 a.m. This beak is also prominent in the summer diagram, occurring, however, nearly an hour earlier. Associated with the beak is an indentation or bay, extending from about 6 p.m. to 7 or 8 a.m. In the summer diagram the curvature is small near the deepest part of the bay, and except at the beak is large only from 6 to 8 p.m. In the diagrams for equinox and the year there is, as it were, a pushing forward of the shore line of the bay from 6 p.m. to midnight, leading to a marked indentation in the early morning hours. This advance of the shore line of the bay in the afternoon hours has so far developed in the winter diagram that all that remains of the bay is the very deep narrow indentation in the early morning hours. The beak is still represented in the winter diagram at 9 a.m., *i.e.*, about an hour later than in the equinoctial diagram, and two hours later than in the summer diagram, but it is now overshadowed by the protuberance near midnight.

The three NV diagrams for the whole year again differ mainly in amplitude. They all show a distinct loop near mid-day, somewhat more developed relatively in the sunspot minimum diagram than in the other two. The sunspot maximum and eleven-year diagrams show also a very small loop near 4 a.m. In the sunspot minimum diagram this is represented by a sort of tail, with its tip at 5 a.m. The hour marks for several hours on end are so nearly on a straight line, that it is impossible to say whether there is a true loop, as in the eleven-year diagram, or a very narrow indentation. The equinoctial diagram very closely resembles that for the eleven years. The summer diagram shows a considerably larger development of the mid-day loop, but the early morning loop has disappeared and is represented by a small tooth. The winter diagram shows development in an opposite direction. The mid-day loop has disappeared, and instead of a loop in the early morning there is a long narrow promontory, which like the rest of the diagram is described anti-clockwise.

A feature in NV diagrams to which attention was called some years ago by

WV vector diagrams.

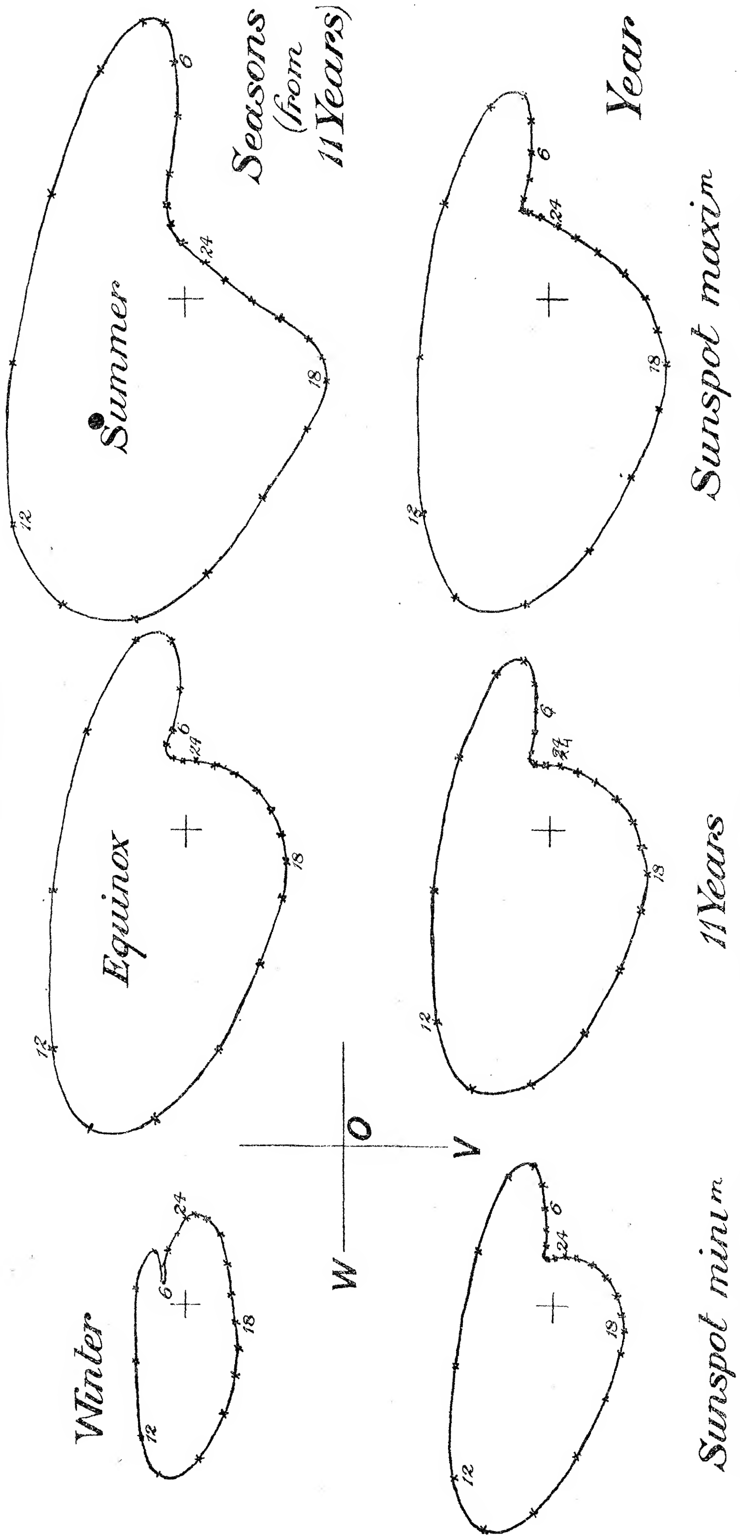

Fig. 11 (upper half). Vector diagrams in vertical plane. Small cross indicates origin of co-ordinates. Arms of large cross 10γ.

NV vector diagrams.

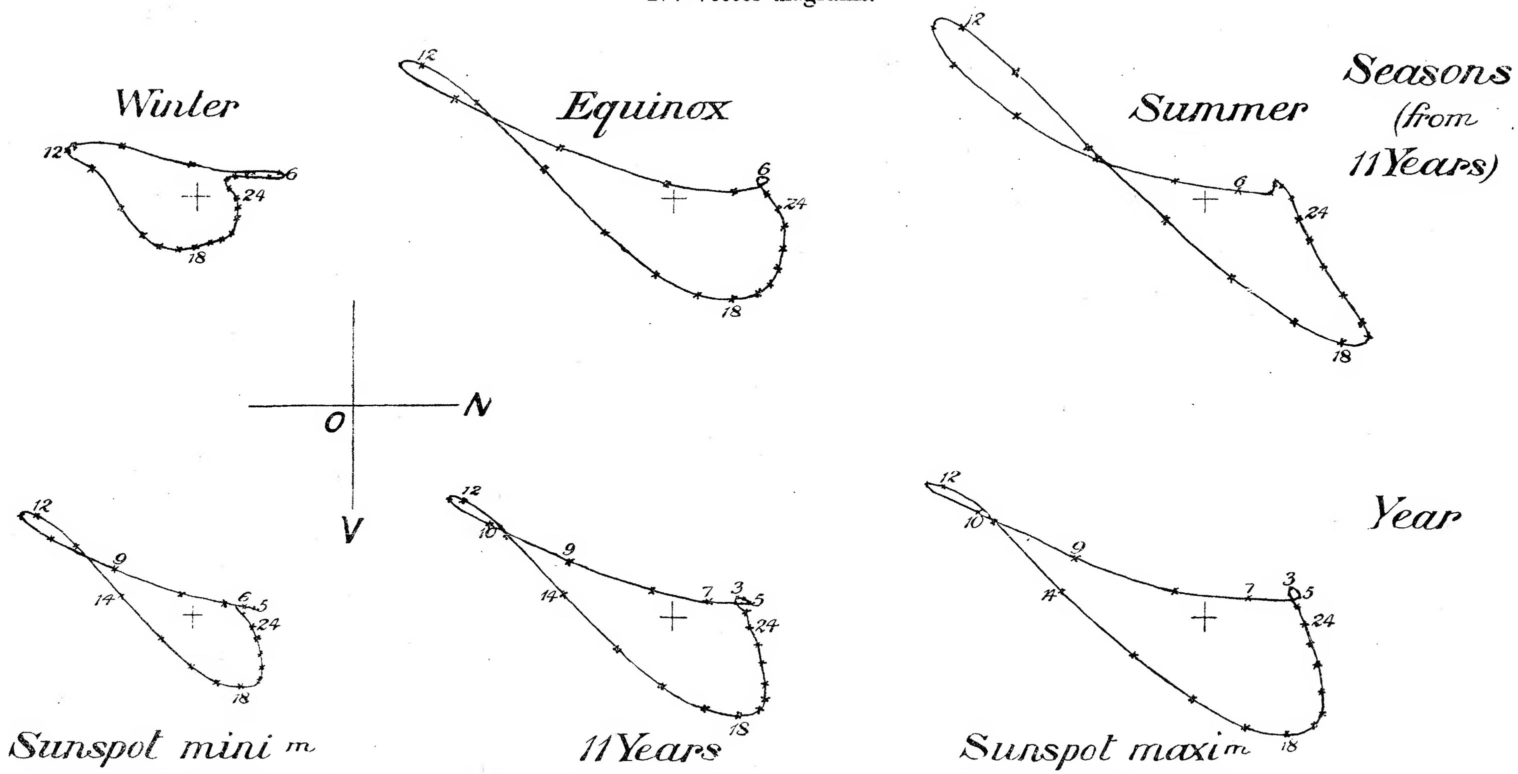

Fig. 11 (lower half). Vector diagrams in vertical plane. Small cross indicates origin of co-ordinates. Arms of large cross 10γ.

Mr. R. B. SANGSTER* is the approach which the diagram makes in the early afternoon hours to a straight line. This feature is prominent in the summer diagram between noon and 4 or 5 p.m. It is also fairly shown in the equinoctial diagram and in the diagrams for the year, especially that from sunspot maximum, but hardly in the winter diagram.

§ 14. Fig. 12 shows ordinary less quiet day difference curves, *i.e.*, the ordinate represents the algebraic excess of the ordinary day over the corresponding quiet day value in the diurnal inequality. All the curves refer to the mean diurnal inequality for the year. In the case of V, T and I there is only one curve, which corresponds to the whole eleven years. In the case of H, N and W there are three curves, representing the sunspot maximum and minimum groups of years in addition to the whole eleven years. The results were not smooth enough to justify drawing curves of continuous curvature. The scale, which is the same for all the force curves, is much more open than in the corresponding ordinary day curves.

In each case the ordinary less quiet day difference curve shows a considerable resemblance in type to the corresponding disturbed less quiet day difference curve given in a previous paper, but its amplitude is very much less.

In the case of the H difference curves in fig. 12 the amplitude is so small that a longer period than eleven years would have been needed to bring out the character fully during the night hours. There is a distinct minimum in the curve near noon—signifying that the principal daily minimum is more developed in the ordinary than in the quiet day curve—but that is perhaps the only unmistakable feature. The irregularities in the sunspot maximum and minimum curves are too great to warrant deductions as to differences between them.

The N, and still more the W, difference curves have a decidedly larger amplitude and are less irregular, especially the 11-year curves. The N difference curve has its mid-day minimum well developed, like the ordinary N curve, but it has a relatively better developed night maximum, and there seems to be no secondary maximum and minimum.

The W difference curve differs markedly from both the ordinary and quiet day curves. There is no morning minimum near 8 a.m., as in the ordinary day curve, and instead of a sharply defined maximum in the early afternoon, there is a wide plateau for some four hours on either side of noon. The largest ordinate appears at 4 p.m., *i.e.*, from two to three hours later than in the ordinary day curve. Whether the saddle near 1 p.m., which is more apparent in the sunspot maximum and minimum than in the 11-year curves, is a real or an accidental feature is open to some doubt.

The V and T difference curves closely resemble one another, as might have been inferred from the fact that the difference between ordinary and quiet day inequalities is much larger for V than for H. The two curves, while quite unlike the ordinary day V and T curves, closely resemble the disturbed less quiet day V difference

* 'Roy. Soc. Proc.,' A, vol. 83, p. 428

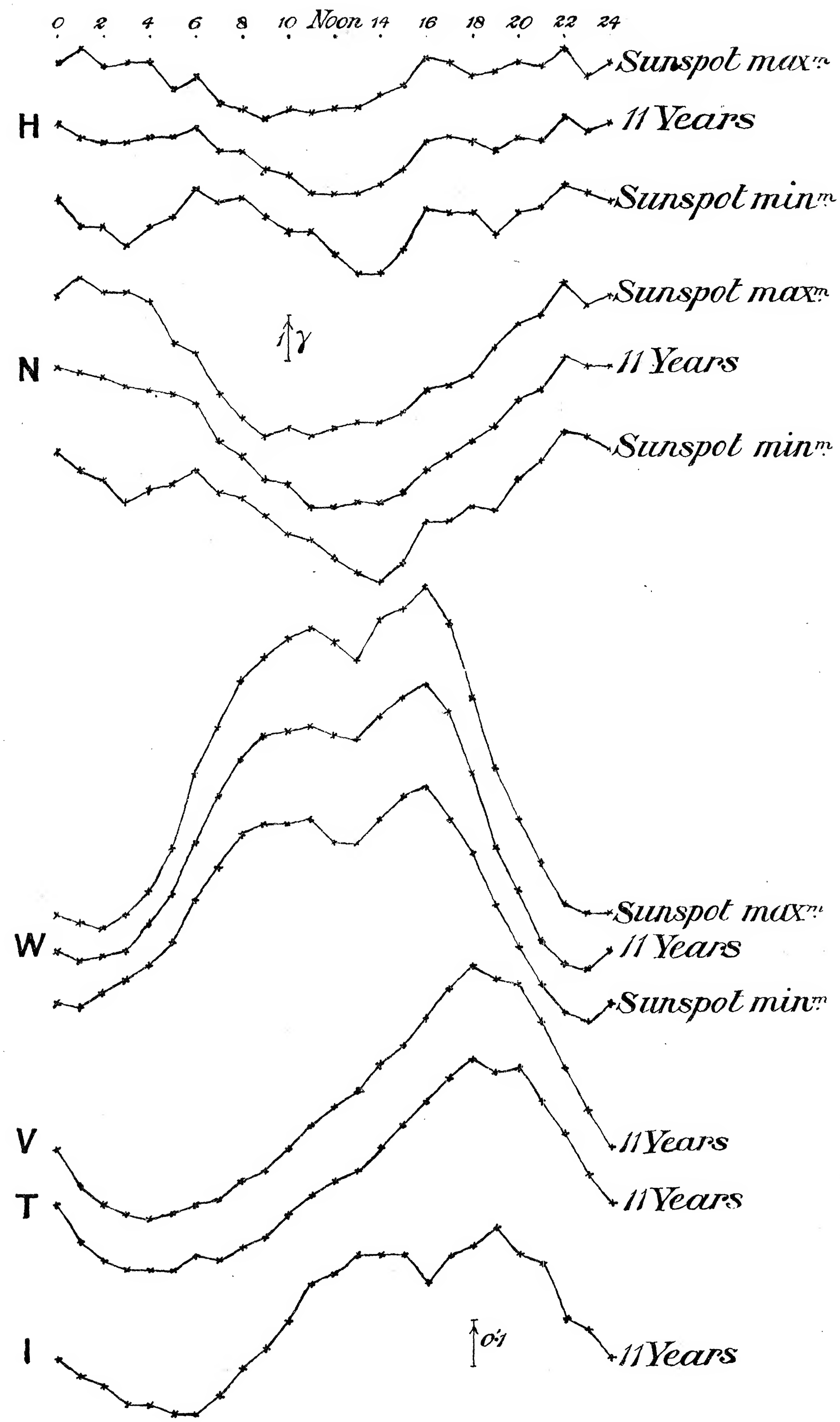

Fig. 12. Difference curves, ordinary less quiet days.

curves. They show one well marked maximum near 6 p.m., and an equally well marked minimum about 4 a.m.

The I difference curve in fig. 12 is also markedly unlike the ordinary day I curve. It has a considerable resemblance to the W difference curve, but corresponding points occur some hours later in the day in the I curve. Some doubt must be entertained as to the reality of the depression shown about 4 p.m.

The difference curves in fig. 12 indicate on the whole an increased amplitude in the ordinary day inequality as compared with that of the quiet day, but they also indicate a distinct difference in type. The nature of the difference is most conveniently considered in connection with the harmonic analysis of the inequalities. One outstanding feature has already been discussed.*

Annual Inequality.

§ 15. Let M represent the mean value of any element for the whole year, and ΔM the algebraic increment in the twelve months due to secular change, then if the secular change took place uniformly throughout the year the mean value of the element during the n^{th} month should be

$$M + (n - \tfrac{1}{2} - 6)\,\Delta M/12,$$

where n represents 1, 2, 3 up to 12.

This neglects the difference in length between different months.

If the actual mean value for the n^{th} month proves to be p_n, the values of

$$p_n - \{M + (n - \tfrac{1}{2} - 6)\,\Delta M/12\}$$

for the 12 months constitute the annual inequality.

If a magnetograph had a known and invariable base line value, the annual inequality of the corresponding element could be determined from curve readings alone. On the other hand, if an absolute instrument were invariably read when the corresponding element had its mean value for the day, the annual inequality could be got without any reference to the curves. But in practice we can tell the base line value of the curve only by reference to the absolute observations, and we cannot tell when the element had its mean value without recourse to the curves.

When base values have been assigned to all the curves, a mean value can be found for each day, representing the mean of the hourly values. From these daily means a monthly mean can be derived, representing, according to the practice of the particular observatory, the mean of all the days of the month, or the mean of all but highly disturbed days, or the mean of a limited number of selected days, *e.g.*, the 5 international quiet days. Unless all days are used, the mean of the days employed may

* 'Roy. Soc. Proc.,' A, vol. 91, p. 370.

not fall at the centre of the month, and a question may arise as to whether some allowance should be made for this. The desirability of selecting the 5 quiet days so that their mean shall fall near the middle of the month is recognised, but such a choice is not always possible.

The practice in vogue at Kew from 1890 to 1900 was to treat the base value of each element as invariable throughout each calendar month, except in so far as it was influenced in the case of H and V by departures of the temperature of the magnetograph magnets from the mean temperature of the month. Using these base values, it would have been possible to deduce mean values depending on all the days, or on all but the highly disturbed days, in the usual way. Having regard to the special circumstances, however, a different method—presently to be described—has been adopted as equally satisfactory and much simpler. It recognises that it is really on the absolute instruments that the accuracy of the annual inequality ultimately depends. The magnetographs serve only to show what allowance has to be made to any individual absolute observation to bring it to what it would have been if taken at an hour when the element in question has its mean value for the day. To take a simple example, suppose we observed the declination daily at noon, and that in the diurnal inequality for a particular month the entry under noon is $+3'\cdot0$. Then to get the mean value of D for that particular month all we have to do is to subtract $3'\cdot0$ from the arithmetic mean of the absolute observations. The correction $-3'\cdot0$ applied to individual noon readings will not in general give exactly the mean value for the day, but so far as the monthly mean is concerned that is immaterial.

If we observe not daily but weekly, the 4 or 5 monthly days of observation at noon may all happen to depart from the average day of the month in the same direction, so that the method if applied to the observations of a single year could hardly claim to be satisfactory. If, however, we deal with the observations not of one but of a number of years, omitting days of large disturbance, accidental features must largely disappear, and this is the course that has been adopted.

The ordinary absolute observation of H consists of two parts, the vibration experiment and the deflection experiment. The mean times of these two experiments were found, and departures at each of them from the mean value for the day were deduced from the diurnal inequality, and the arithmetic mean of the two was applied with appropriate sign as a correction to the observed value of H. The inequalities, it will be remembered, were calculated for each individual month for H (and V). When the curves were considerably disturbed at the time of an absolute observation—not, of course, a frequent event—the observation was simply omitted. As highly disturbed days had also been omitted from the ordinary day diurnal inequalities, we may reasonably regard these inequalities as appropriate for the correction of the absolute observations.

It had not been the practice to commence the H observation at a fixed hour, and the time required for the deflection experiment varies somewhat according as

observing conditions are more or less favourable. Still in most months the mean times of the vibration and deflection experiments fell so nearly at fixed hours that one might have applied the same correction to each observation, basing it on a mean time from all the observations. As a matter of fact, however, this simplification was not adopted when dealing with the 11 years 1890 to 1900. After 1900, as already explained, magnetic conditions were less favourable at Kew. Still electric tram disturbances are, on the whole, of a nature calculated to impair the accuracy of individual observations rather than that of the arithmetic mean of a number of observations. It thus appeared worth while investigating the annual inequality deducible from absolute observations made in years subsequent to 1900.

As corresponding diurnal inequalities from ordinary days were not available, the corrections applied to the absolute observation results to bring them to the mean value for the day were based on the inequalities of the years 1890 to 1900. In the case of H, the years 1901, 1902, 1903, 1910, 1911, 1912, and 1913, having a mean sunspot frequency of 8·8, had corrections applied from Table VII., which is based on the years 1890, 1899, and 1900, with a mean sunspot frequency of 9·6. The years 1905, 1906, and 1907, having a mean sunspot frequency of 59·9, had corrections applied from Table VI., which is based on the years 1892 to 1895, with a mean sunspot frequency of 75·0. The two years 1904 and 1909, having sunspot frequencies of 42·0 and 43·9 respectively, had corrections applied from Table V. for the 11 years 1890 to 1900, with a mean sunspot frequency of 41·7. The year 1908 was omitted, because the deflection distances were increased from two to three at midsummer, and this possibly might have introduced some discontinuity. The final outcome was that the twelve years dealt with had corrections applied as if their mean sunspot frequency were 31, whereas it was really 27. As we shall see later, the amplitude of the diurnal inequality in H and the sunspot frequency are connected, at least approximately, by a linear relationship. Extrapolation from one period of years to another is of course always a matter of some uncertainty; still there is considerable ground for believing that the accuracy of the inequality derived from the second period of years is not greatly inferior to that derived from the first.

In the case of I the observation had been taken almost invariably in the afternoon, the mean time of observation falling within 30 minutes of 3 p.m. Near this hour I changes slowly, and its departure from the mean value for the day is not large. To have got out diurnal inequalities of I for each month of the 11 years would have entailed an immense amount of labour. Thus corrections to the observed values were simply derived from the mean inequalities from the 11 years given in Table XIV., and the corrections were calculated for the mean time of all the observations of the month, not for the times of the individual observations, unless these times varied more than was generally the case. The I observational data from the 14 years 1901 to 1914 were similarly treated, use being again made of the diurnal inequalities in Table XIV.

§ 16 Values having been obtained from the absolute observations of each month corrected for diurnal variation, the means for all the months of the same name were summed and meaned, the 11-year period and the later period being treated separately. The monthly means thus obtained represented the average annual change from mid-January to mid-December, comprising the annual inequality and the secular change. It remained to eliminate the secular change.

In the case of the 11-year period, the mean annual secular change of H between 1890·5 and 1900·5 derived from the quiet days was $+25{\cdot}9\gamma$. A small difference has been observed at several stations between mean annual values of H derived respectively from quiet days and from all or all ordinary days, the former mean exceeding the latter. The difference, however, is only of the order 3γ, and as 1890 and 1900 were both quiet years of very similar character, any uncertainty of this kind spread over a 10-year period must have been negligible. A confirmation of the accuracy of the quiet day estimate was derived by taking arithmetic means for 1890 and 1900 of the twelve monthly means of the absolute observations, corrected for diurnal variation. The mean thus obtained for 1900 exceeded that obtained for 1890 by $259{\cdot}5\gamma$, giving $+25{\cdot}9_5$ for the mean secular change.

In the case of the second group of years, the mean secular change in H—as obtained from the annually published quiet day results, allowing for changes of constants and procedure—was only $+5{\cdot}8_2\gamma$. In the case of I the mean secular changes accepted were $-2'{\cdot}25_5$ for the first period and $-1'{\cdot}05_5$ for the second.

The substitution of these respective values for ΔM in the formula in § 15 led to the annual inequalities for H and I given in Table XVIII. The annual inequalities given for V in that table were calculated from the formula expressing changes in V in terms of changes in H and I, employing mean values for the numerical coefficients of ΔH and ΔI. At the foot means are given for the ordinary three seasons. The centre of each season falls at the middle of the year, so these seasonal values are unaffected by the secular change, or by any error that may have been made in estimating its amount.

The greater or less smoothness of the inequalities, and the amount of accordance between the results from the two periods, are the chief criteria for estimating the reliability of the data in Table XVIII. Both criteria are less favourable towards the inequality in V than towards those in H and I. The V inequality from the 11-year period is very irregular, plus and minus signs occurring rather promiscuously; and while the corresponding seasonal means from the two periods agree in sign, the winter and summer means from the second period are numerically much larger than those from the first. The lesser consistency of the V inequality is hardly surprising since it suffers from every uncertainty or accident that affects either the H or the I inequality. A change of 10γ in H alters I as much as a change of 24γ in V. Thus the deduction of changes in V from the combination of observed changes in I and H, though the only way feasible, does not promise high accuracy.

There is a regularity in both sets of figures for H which can hardly be accidental. They agree in making the successive monthly values all positive from May to August, and all negative from September to February. Both periods show a clear maximum in the summer months, but one puts the minimum in winter, the other in equinox. The inequality obtained by combining the two periods, allowing them equal weights, makes the winter and equinoctial values practically equal. It shows a range of 12·5γ, the maximum coming in June, and the minimum in November.

TABLE XVIII.—Annual Inequality.

Month and season.	Horizontal force.			Inclination.			Vertical force.		
	First period.	Second period.	Mean.	First period.	Second period.	Mean.	First period.	Second period.	Mean.
	γ	γ	γ	′	′	′	γ	γ	γ
January . . .	−2·0	−1·8	−1·9	+0·19	0·00	+0·09	+1·9	− 4·4	−1·2
February . . .	−0·1	−1·6	−0·9	+0·03	+0·06	+0·04	+0·8	− 1·8	−0·5
March.	−4·5	+3·5	−0·5	+0·41	−0·07	+0·17	+4·1	+ 6·0	+5·0
April	−2·3	+0·5	−0·9	+0·08	+0·09	+0·08	−2·6	+ 4·4	+0·9
May.	+3·1	+5·6	+4·3	−0·08	−0·17	−0·12	+4·7	+ 7·3	+6·0
June	+8·8	+7·0	+7·9	−0·56	−0·16	−0·36	+1·0	+10·9	+5·9
July	+2·6	+2·3	+2·5	−0·26	−0·18	−0·22	−3·0	− 0·8	−1·9
August	+4·4	+0·5	+2·5	−0·23	−0·07	−0·15	+2·2	− 1·3	+0·4
September . .	−4·2	−2·7	−3·4	+0·12	−0·06	+0·03	−5·6	− 8·5	−7·1
October	−3·4	−3·7	−3·6	+0·25	+0·14	+0·19	+0·8	− 4·0	−1·6
November. . .	−1·9	−7·3	−4·6	+0·21	+0·36	+0·29	+3·0	− 4·4	−0·7
December. . .	−0·9	−1·7	−1·3	−0·16	+0·06	−0·05	−8·0	− 2·2	−5·1
Winter	−1·2	−3·1	−2·2	+0·07	+0·12	+0·09	−0·6	− 3·2	−1·9
Equinox. . . .	−3·6	−0·6	−2·1	+0·22	+0·03	+0·12	−0·8	− 0·5	−0·7
Summer. . . .	+4·7	+3·8	+4·3	−0·28	−0·14	−0·21	+1·2	+ 4·0	+2·6

In the case of I the two periods agree in showing a distinct minimum in summer, but the one places the maximum in winter, the other in equinox. Combining the two periods, allowing them equal weight, we get a comparatively smooth inequality with a range of 0′·65, the maximum coming in November, the minimum in June. The type is on the whole fairly similar to that of results that have been published for Parc St. Maur and Potsdam, and for the northern hemisphere as a whole by LIZNAR and HANN, but the range shown in Table XVIII. is a good deal less than in the cases quoted.

Assuming that the phenomena are not of instrumental origin, it seems reasonably certain, after allowing for a secular change progressing at a uniform rate throughout the year, that H is higher and I lower in summer than in winter. Also it seems probable, though more open to doubt, that V displays the same phenomena as H. This agrees with the results obtained from quiet days alone in a previous paper.

§ 17. The possibility that the phenomena owe something to instrumental causes must be recognised. If there is any instrumental cause at work, it is presumably of thermal origin. In the case of I, any sensible temperature effect on the absolute observations is difficult to imagine. The strength of the dip needles, it is true, may not be the same, when they are stroked at 25° C. as when they are stroked at 10° C. I have no statistics on the subject. Also the distance of the centre of gravity from the axis of suspension will naturally increase with rise of temperature. Thus there would be nothing very surprising if the inclination observed with one particular end of the needle dipping varied slightly with temperature. But the reversal of the poles, invariably observed at Kew, ought to eliminate this as a first approximation, leaving only second order terms, which one would not expect to be sensible. The absolute observation hut at Kew is heated by a lamp in cold weather, so that the difference between summer and winter temperatures of observation is only of the order of 10° C. For the diurnal inequality in I we are dependent on the H and V magnetographs, the latter of which has a large temperature coefficient. An error in the value accepted for that coefficient, or in the results accepted for the diurnal variation of temperature of the V magnet, might introduce a differential error as between summer and winter. Any such error would affect the accuracy of the corrections applied to the observed inclinations to reduce them to the mean value for the day. The hour at which the observations is taken is, however, one at which the change is not rapid either in the inclination or in the temperature of the magnetograph room. Thus any considerable error seems improbable.

§ 18. In the case of H, the ways in which temperature might come in are more numerous. There might be an error in the temperature coefficient of the collimator magnet, but the consequences of this would not be nearly so serious as might appear at first sight. What really concerns us in this connection is not the mean temperature of the whole H observation, but only the difference between the temperatures in the vibration and deflection experiments, which is usually only 1° or 2° C. In the present case, moreover, the error would come in not on the average size of this difference, but only on its seasonal variation. Temperature practically always rises during an H observation, and so is higher during the deflection experiment, which comes last, than during the vibration experiment. If there were no artificial heating the difference would naturally be greatest in summer, so a seasonal differential error is conceivable. If it existed, however, it should show itself in an apparent seasonal variation in the values found for the magnetic moment of the collimator magnet reduced to 0° C., and a special investigation showed no trace of this.

Errors in the values assumed for the variation with temperature of the length of the deflection bar and the moment of inertia of the collimator magnet would come in on the full annual range of temperature in the magnetic hut, but coefficients of thermal expansion in brass and steel are small quantities, and any large percentage error in them is most improbable. The temperature coefficient of the H magnetograph is

small, and the general accordance of individual H observations and curve measurements seems to preclude the possibility of any large percentage error in the value accepted.

There is, in short, no direct evidence of the existence of uncorrected temperature effects, while there is a good deal in favour of the substantial accuracy of the allowances made. At the same time, direct experiment, if possible without undue risk of interfering with the records, would be desirable.

Fourier Coefficients.

§ 19. The analysis of the diurnal inequalities into series of harmonic terms whose periods are 24, 12, &c., hours is part of the regular routine at some observatories. To some people circular functions seem on a wholly superior plane to all others, and the analysis of diurnal inequalities according to any other type of function would appear almost inconceivable. Others may argue that the employment of circular functions for the representation of magnetic diurnal inequalities may hide rather than reveal what is of real physical importance. There are several common-sense arguments in favour of the analysis in series of sines and cosines. The use of these is so very general that for the intercomparison of results at different stations there is really no competing series. Again, it is found that as a rule 4 Fourier waves—*i.e.*, terms with periods of 24, 12, 8 and 6 hours—suffice to give a very close approximation to the observed diurnal inequality, and the 8-hour and 6-hour waves are usually small compared with the first two. There is thus a good deal to be said for the argument that the Fourier analysis is a natural one. This argument of course would lose much of its force if a single function of the time, of a not unduly complicated form, with only 2 or 3 parameters sufficed to represent the diurnal inequality adequately at a number of stations. But until such a function has been proved to exist, the course which is followed here of employing ordinary Fourier series is likely to commend itself to the majority.

The diurnal inequality is usually expressed in one of the alternative forms

$$a_1 \cos t + b_1 \sin t + a_2 \cos 2t + b_2 \sin 2t + \ldots$$
$$c_1 \sin (t + \alpha_1) + c_2 \sin (2t + \alpha_2) + \ldots,$$

where t represents time counted from midnight, one hour in t being taken as the equivalent of 15°. The constants a, b of the first series, or c, α of the second, are generally called Fourier coefficients, c representing the amplitude and α the phase angle. The usual process is to calculate the a, b constants from the hourly values in the diurnal inequality, and then deduce the c, α constants from the equations

$$\tan \alpha = a/b, \quad c \equiv \sqrt{a^2+b^2} = a/\sin \alpha = b/\cos \alpha.$$

If a, b coefficients have been calculated for three magnetic elements, they can be deduced at once for any other element, through the formula expressing it in terms of

the first three. Thus it sufficed to calculate the a, b coefficients in the usual way for D, H and V, and the work so far as D is concerned had been already done.

The values of a and b for the year, or for any season, are the arithmetic means of the values from the included months. They can thus be deduced at pleasure from the values of a and b calculated for the included months, or be specially calculated from the inequality for the season. The employment of both methods puts the accuracy of the calculations to a very severe test. In fact, to secure agreement to say three significant figures it is necessary to carry the calculation at least one place further. This test was not in general applied, but all the calculations were carefully checked, special attention being given to any apparent irregularities.

TABLE XIX.—Horizontal Force (Local Mean Time for Phase Angles).

Year.	c_1.	α_1.	c_2.	α_2.	c_3.	α_3.	c_4.	α_4.
	γ.	°	γ.	°	γ.	°	γ.	°
1890	6·81	119·2	4·01	312·4	2·18	175	1·13	28
1891	9·66	117·1	5·62	303·7	2·37	166	1·02	23
1892	13·00	117·2	6·52	301·6	2·81	166	1·32	22
1893	13·35	114·1	7·45	301·7	3·26	163	1·33	18
1894	13·26	113·9	7·09	294·9	2·60	167	1·26	24
1895	11·73	113·3	6·15	298·9	2·57	171	1·20	22
1896	9·81	114·8	5·22	297·2	2·48	166	1·24	17
1897	8·56	112·3	4·61	294·8	1·99	173	1·30	28
1898	8·36	115·9	4·14	302·1	2·17	166	1·04	25
1899	8·10	115·8	4·09	302·5	2·36	174	1·10	32
1900	6·56	119·0	3·85	306·7	2·16	178	1·12	20

Tables XIX. and XX. give the amplitudes and phase angles for the 24-, 12-, 8- and 6-hour terms in the H and V mean diurnal inequalities for the whole year, each of the eleven years being treated separately.

TABLE XX.—Vertical Force (Local Mean Time for Phase Angles).

Year.	c_1.	α_1.	c_2.	α_2.	c_3.	α_3.	c_4.	α_4.
	γ.	°	γ.	°	γ.	°	γ.	°
1890	5·08	139·4	3·39	273·3	1·36	106	0·47	282
1891	6·84	145·1	4·79	272·1	1·64	96	0·60	295
1892	8·10	148·8	5·29	268·5	1·77	101	0·69	280
1893	7·26	138·8	5·62	270·1	2·26	97	0·71	279
1894	8·38	145·8	5·32	269·0	2·02	95	0·60	292
1895	7·70	148·1	5·09	271·6	1·83	97	0·68	295
1896	7·54	143·5	4·60	270·6	1·78	105	0·61	284
1897	7·07	138·5	3·95	268·6	1·48	101	0·52	286
1898	6·95	142·7	4·25	274·2	1·50	108	0·49	286
1899	6·00	144·0	3·87	271·3	1·31	107	0·52	284
1900	5·38	130·0	3·48	276·1	1·60	103	0·61	281

G.M.T. was employed, as already stated, in the diurnal inequalities, and thus the values deduced in the first instance for the Fourier coefficients referred to G.M.T. Local mean time is, however, more generally instructive, and accordingly the necessary transference to local time has been made in Tables XIX. and XX., and all the subsequent tables relating to Fourier coefficients. The transference does not affect the amplitudes. The corrections it requires to the phase angles are

$$+19' \text{ in } \alpha_1, \ +38' \text{ in } \alpha_2, \ +57' \text{ in } \alpha_3 \text{ and } +1^\circ\ 16' \text{ in } \alpha_4,$$

Kew local time being the equivalent of 19′ after Greenwich.

The relation with sunspots will be discussed more fully later, but the significance of the tables will be better understood if regard is paid to the following facts. 1890 was a year of sunspot minimum with a frequency of 7·1. The frequency rose rapidly to a maximum of 84·9 in 1893, and fell more slowly to 9·5 in 1900. In 1898 there was a slight arrest in the fall, the mean frequency being 26·7 as compared with 26·2 in 1897. The year 1893, though the year of sunspot maximum, was on the whole a quiet year free from large disturbances, much quieter than 1892, 1894 or 1895.

In Table XIX. c_1, c_2, c_3 and c_4 all rise to a maximum in 1893, and the general parallelism with the sunspot variation is readily seen, especially in c_1 and c_2. Table XX. shows a similar state of matters, except that the value of c_1 in 1893 fell short of that in several adjacent years.

The variation in the phase angle is by no means so decisive. In Table XIX. the largest values of α_1 and α_2 are associated with the years of sunspot minimum, but the smallest values occur in 1897, an intermediate year as regards sunspots. Accident seems to play a sensible part in the relation between phase angles in successive years, especially in the case of α_3 and α_4. The same remark applies in even greater measure to Table XX.

In fact the influence of sunspot frequency on the phase is so small that for its study it is desirable to combine the years in groups representative respectively of large and small sunspot frequency, in hopes of eliminating accidental features.

§ 20. Tables XXI. and XXII. show the variation in amplitude and phase angle throughout the year in the Fourier waves representing the diurnal inequality in H, and Tables XXIII. and XXIV. do the same for V. Results are given for the whole 11 years, also for 1890, 1899 and 1900 representing few sunspots, and 1892 to 1895 representing many sunspots. Arithmetic means from the 12 months are given in Tables XXI. and XXIII. When there is considerable variation of phase throughout the year, contributions from different months to the seasonal and yearly diurnal inequalities to some extent neutralise one another. Thus frequently a better idea of the average activity of the forces to which any particular Fourier wave is due is derivable from the arithmetic mean of the c's than from the corresponding c in the mean diurnal inequality for the year.

TABLE XXI.—Horizontal Force. (Unit 1γ.)

Month.	c_1.			c_2.			c_3.			c_4.		
	S. minimum.	11 years.	S. maximum.	S. minimum.	11 years.	S. maximum.	S. minimum.	11 years.	S. maximum.	S. minimum.	11 years.	S. maximum.
January . . .	1·23	3·15	5·41	1·80	3·41	4·46	2·27	2·26	2·52	1·16	1·29	1·33
February. . .	2·93	4·50	6·33	2·46	3·54	5·02	2·45	2·68	3·14	1·31	1·26	1·18
March	6·55	9·13	11·78	4·31	5·66	7·46	3·39	3·75	4·53	1·44	1·63	1·88
April.	10·27	14·43	18·44	5·37	7·55	9·20	3·17	3·61	4·17	1·32	1·65	2·09
May	12·21	15·83	19·14	4·94	6·44	8·11	1·32	1·25	1·57	0·86	1·04	1·18
June	13·18	17·18	21·56	5·58	7·06	9·26	1·85	1·73	2·45	0·88	0·71	0·96
July	12·94	17·17	21·86	4·83	7·06	9·10	2·36	2·01	1·99	0·95	0·73	0·88
August. . . .	12·41	15·97	19·70	4·74	6·35	7·90	3·12	3·18	3·44	1·40	1·43	1·32
September . .	10·60	13·17	15·31	5·05	5·71	6·33	3·63	3·84	3·96	1·84	1·88	1·97
October . . .	8·03	10·89	13·88	4·88	6·14	8·02	2·72	3·66	4·30	1·13	1·62	1·91
November . .	3·05	5·20	7·98	3·72	4·54	5·68	1·85	2·21	2·61	0·92	1·13	1·18
December . .	2·66	3·30	4·73	2·59	3·32	4·25	1·53	1·62	2·07	0·67	0·57	0·46
Arithmetic means .	8·01	10·83	13·84	4·19	5·56	7·07	2·47	2·65	3·06	1·16	1·25	1·36

In the case of c_1 and c_2, whether in Table XXI. or Table XXIII., there is no single month in which the amplitude fails to show an increase as we pass from the sunspot minimum to the sunspot maximum group of years. In the case of c_3 and c_4 the same is generally true, but there are a few exceptions, presumably accidental in both tables.

TABLE XXII.—Horizontal Force. Phase Angles referred to Local Mean Time.

Month.	a_1.			a_2.			a_3.			a_4.		
	S. minimum.	11 years.	S. maximum.	S. minimum.	11 years.	S. maximum.	S. minimum.	11 years.	S. maximum.	S. minimum.	11 years.	S. maximum.
	° ′	° ′	° ′	° ′	° ′	° ′	°	°	°	°	°	°
January	−24 24	51 43	67 12	298 41	282 8	279 30	167·5	157·9	152·1	8·5	3·5	−2·7
February.	69 21	70 49	77 46	280 32	269 56	271 57	146·7	146·3	141·2	−9·4	−5·2	5·9
March	103 28	101 8	102 29	297 55	294 15	295 28	154·0	153·5	153·6	0·4	−1·4	−6·2
April	115 32	114 51	115 30	299 0	297 51	297 45	145·3	150·1	152·3	13·1	20·4	20·3
May	132 15	131 27	130 17	317 28	307 52	302 44	217·0	204·5	198·5	59·9	67·0	63·3
June	131 37	134 43	136 25	306 54	308 24	312 5	200·8	213·3	216·0	37·0	53·3	67·2
July	134 16	134 5	134 20	321 2	310 37	307 59	204·5	191·9	179·9	42·1	30·1	30·8
August	129 21	127 58	126 44	338 46	327 27	322 17	212·4	203·8	197·8	32·2	33·9	24·7
September	116 18	113 58	111 58	320 32	320 48	318 10	187·8	188·3	188·7	34·6	33·5	38·0
October	94 47	94 30	93 43	294 57	295 57	297 8	162·8	162·9	160·8	25·4	21·3	16·2
November	80 37	76 20	77 37	289 21	282 28	279 45	158·9	153·9	149·1	40·7	24·0	6·8
December	13 50	37 45	54 31	280 16	268 59	265 50	145·6	141·8	134·2	34·3	15·8	4·4

The annual variation in the amplitude is clearly shown in all cases, but it follows different laws in the different waves. c_1 and c_2 in both H and V have a well marked

minimum near midwinter and a maximum near midsummer. c_3 and c_4 also exhibit a minimum near midwinter, but there is a second minimum—which in the case of c_3 in

TABLE XXIII.—Vertical Force. (Unit 1γ.)

Month.	c_1.			c_2.			c_3.			c_4.		
	S. minimum.	11 years.	S. maximum.	S. minimum.	11 years.	S. maximum.	S. minimum.	11 years.	S. maximum.	S. minimum.	11 years.	S. maximum.
January . . .	2·72	3·53	4·39	1·10	1·32	1·70	0·51	0·57	0·71	0·28	0·44	0·54
February. . .	3·88	5·01	5·98	1·94	2·72	3·29	1·03	1·31	1·58	0·36	0·47	0·63
March	5·70	7·03	7·26	4·21	5·37	6·24	2·17	2·44	2·78	0·94	0·98	1·04
April.	7·81	8·39	8·50	5·38	6·49	7·47	2·24	2·75	3·03	0·70	0·82	0·87
May	9·28	10·88	12·18	6·02	7·62	9·26	1·93	2·10	2·25	0·52	0·63	0·60
June	8·49	10·33	11·49	5·28	6·65	8·22	1·27	1·42	1·80	0·47	0·36	0·32
July	8·76	11·07	13·54	5·12	6·38	7·55	1·40	1·66	2·01	0·43	0·37	0·37
August. . . .	5·61	7.37	7·78	5·27	6·21	6·75	2·05	2·47	2·89	0·62	0·62	0·64
September . .	5·89	7·64	8·35	3·90	4·86	5·34	1·96	2·07	2·25	0·85	0·81	0·91
October . . .	3·90	5·78	7·27	2·07	3·49	4·17	1·59	1·89	2·29	0·86	1·04	1·18
November . .	3·08	4·47	5·32	1·61	2·11	2·64	0·74	1·00	1·32	0·61	0·68	0·80
December . .	1·79	2·95	4·02	0·88	1·26	1·78	0·53	0·78	1·06	0·10	0·21	0·41
Arithmetic means .	5·58	7·04	8·01	3·56	4·54	5·37	1·45	1·70	2·00	0·56	0·62	0·69

Table XXI. is actually the principal minimum—near midsummer. The largest values in c_3 and c_4 present themselves in equinoctial months.

TABLE XXIV.—Vertical Force. Phase Angles referred to Local Mean Time.

Month.	α_1.			α_2.			α_3.			α_4.		
	S. minimum.	11 years.	S. maximum.	S. minimum.	11 years.	S. maximum.	S. minimum.	11 years.	S. maximum.	S. minimum.	11 years.	S. maximum.
	°	°	°	°	°	°	°	°	°	°	°	°
January . . .	164·1	160·8	157·9	287·9	283·4	275·0	145	118	101	267	277	281
February . .	154·6	155·7	154·5	269·8	275·9	278·1	104	100	98	237	261	282
March	133·3	143·9	150·3	272·7	270·7	268·6	94	93	87	268	275	282
April.	121·8	130·5	132·1	265·4	263·3	260·3	95	94	92	293	300	298
May	126·9	129·3	129·5	274·9	270·3	268·4	103	102	99	302	314	327
June	136·2	139·5	140·9	271·2	268·9	268·3	107	100	98	307	315	307
July	145·2	142·8	146·3	266·3	263·6	262·7	91	82	78	260	245	219
August. . . .	128·8	134·5	136·3	276·8	273·5	273·5	104	102	101	285	280	281
September . .	139·4	143·1	145·3	279·4	276·6	277·7	116	109	108	290	297	298
October . . .	141·7	149·5	153·6	267·2	269·5	267·6	102	102	95	281	287	284
November . .	170·4	171·8	174·6	308·7	297·1	292·5	138	125	108	302	286	278
December . .	143·0	155·9	163·7	281·2	274·3	269·4	125	119	120	306	267	269

In the case of the phase angles the difference between sunspot maximum and minimum years is much less decisive. α_3 in V in every month of the year is larger—*i.e.*, speaking generally, the maximum occurs earlier in the day—in sunspot minimum than in sunspot maximum. There is also a large preponderance of months in which the sunspot minimum angle is the larger in the cases of α_3 in H and of α_2 in both H and V. α_1, however, in V shows exactly the opposite phenomenon, while α_1 in H and α_4 in both H and V show no decided tendency.

In H all four phase angles exhibit the same tendency in their annual variation. They are distinctly larger in summer than in winter. This is especially conspicuous in the case of α_1; in sunspot minimum the phases of the 24-hour term in January and July approach opposition.

An increase in phase angle means in a general sense an earlier occurrence in the maximum and minimum, but this requires special interpretation at times. Take, for instance, the 11-year values of α_1 in H. In January and February the values are respectively $51^\circ\ 43'$ and $70^\circ\ 49'$. The corresponding times of occurrence of the maximum are respectively

$$\text{In January } t = (90-51{\cdot}72)/15 = 28{\cdot}28/15 = 1{\cdot}89 \text{ hour} = 1 \text{ hour } 53 \text{ minutes.}$$

$$\text{In February } t = (90-70{\cdot}82)/15 = 19{\cdot}18/15 = 1{\cdot}28 \text{ hour} = 1 \text{ hour } 17 \text{ minutes.}$$

But when we pass to March the phase angle $101^\circ\ 8'$ falls in a different quadrant, and the time of the maximum is given by

$$t = (450-101{\cdot}13)/15 = 23{\cdot}3 \text{ hour} = 23 \text{ hours } 18 \text{ minutes.}$$

In a sense the maximum has become earlier in March, only it has as it were transferred itself to the previous day; the wave, in fact had already passed its maximum when the day commenced. The minima in the three months occur in January at 13 hours 53 minutes, in February at 13 hours 17 minutes, and in March at 11 hours 18 minutes. Thus the statement that the minimum has become earlier as the phase angle increased was in this case literally true.

In the case of V in Table XXIV. the annual change is on the whole in the opposite direction to that in H, the angles α_1, α_2 and α_3 being all smaller in summer than in winter. There seems to be a very appreciable accidental element in the values obtained for individual months, especially in the case of α_4.

The mode of annual variation of the amplitudes of the several Fourier waves is best shown by expressing the values for different months as fractions of their arithmetic mean. This has been done for the full 11-year results in Table XXV., data being given for both H and V. The laws of annual variation for the two elements proved sufficiently alike to encourage the formation of the arithmetic means from the two. These arithmetic means are considerably smoother than the data from H or V alone.

Relatively considered, the amplitudes of the first four Fourier waves show a fairly similar range of annual variation. On the whole the range is largest in c_1 and least in c_3; but c_3 and c_4, having a double annual period, vary most rapidly.

TABLE XXV.—Ratios to Arithmetic Mean (11 years' data).

Month.	c_1.			c_2.			c_3.			c_4.		
	H.	V.	Mean.	H.	V.	Mean.	H.	V.	Mean.	H.	V.	Mean.
January . . .	0·29	0·50	0·40	0·61	0·29	0·45	0·85	0·33	0·59	1·03	0·72	0·87
February . .	0·42	0·71	0·56	0·64	0·60	0·62	1·01	0·77	0·89	1·01	0·75	0·88
March	0·84	1·00	0·92	1·02	1·18	1·10	1·41	1·43	1·42	1·31	1·58	1·45
April.	1·33	1·19	1·26	1·36	1·43	1·39	1·36	1·61	1·49	1·32	1·32	1·32
May	1·46	1·55	1·50	1·16	1·68	1·42	0·47	1·23	0·85	0·83	1·02	0·93
June	1·59	1·47	1·53	1·27	1·46	1·37	0·65	0·83	0·74	0·57	0·58	0·57
July	1·59	1·57	1·58	1·27	1·41	1·34	0·76	0·97	0·87	0·59	0·60	0·59
August . . .	1·48	1·05	1·26	1·14	1·37	1·25	1·20	1·45	1·32	1·15	1·00	1·08
September . .	1·22	1·09	1·15	1·03	1·07	1·05	1·45	1·21	1·33	1·51	1·31	1·41
October . . .	1·01	0·82	0·91	1·10	0·77	0·94	1·38	1·11	1·25	1·30	1·68	1·49
November . .	0·48	0·64	0·56	0·82	0·46	0·64	0·84	0·58	0·71	0·91	1·10	1·01
December . .	0·30	0·42	0·36	0·60	0·28	0·44	0·61	0·46	0·53	0·46	0·34	0·40

§ 21. Fourier coefficients were not calculated for the individual months of the year except for H and V. For the other elements they were calculated only for the diurnal inequalities from the seasons and the year. Table XXVI. compares the amplitudes in these seasonal diurnal variations for H, V, T, N, W, and I, use being made in dealing with N and W of the results previously obtained for D. In the case of c_1 and c_2 the equinoctial value is always intermediate in size between the winter and summer values, and somewhat in excess of the value for the whole year. In the case of c_3 and c_4 the equinoctial value is invariably in excess of both the winter and summer values, and much in excess of the value for the year. In the case of c_3 the summer value is the lowest for two elements, N and H; in the case of c_4 the winter value is less than the summer value in no element except I.

In the case of all the Fourier waves for the three rectangular components V, N, and W, the year value of the amplitude is largest in W and least in V. This is in general true also of the three seasonal values, but in equinox c_1 is larger in N than in W, and there are one or two cases in which the V value is not the lowest.

Table XXVII. shows the ratios borne by the amplitudes of the 12-, 8-, and 6-hour waves to the amplitude of the corresponding 24-hour wave. In the case of H, T, N, and I, the importance of the 12-, 8-, and 6-hour waves falls relative to that of the 24-hour wave as we pass from winter to equinox, and from equinox to summer; but in W and V the relative importance of the shorter period waves is greatest in equinox, and in the case of the 12-hour wave it is least in winter.

TABLE XXVI.—Amplitudes of Fourier Waves (11 years' data). (Unit 1γ in Force Components.)

Element.	c_1.				c_2.				c_3.				c_4.			
	Year.	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.
H	9·94	3·90	11·77	16·52	5·34	3·68	6·02	6·66	2·44	2·18	3·59	2·03	1·18	1·04	1·66	0·95
V	6·91	3·96	7·16	9·87	4·51	1·83	5·03	6·70	1·68	0·90	2·27	1·89	0·59	0·44	0·90	0·44
T	9·92	3·72	10·67	15·44	6·02	3·09	6·76	8·22	2·08	1·58	2·95	1·71	0·67	0·56	1·04	0·42
N	12·11	6·76	14·66	16·51	6·31	4·29	7·16	7·79	2·18	2·25	3·21	1·19	0·82	0·77	1·18	0·73
W	13·43	8·65	13·95	19·52	8·76	4·60	10·11	11·94	4·30	2·36	5·80	4·83	1·64	1·60	2·49	0·84
I	0'·500	0'·298	0'·629	0'·829	0'·255	0'·195	0'·302	0'·337	0'·153	0'·126	0'·220	0'·158	0'·082	0'·071	0'·113	0'·077

TABLE XXVII.—Ratios of Amplitudes of Fourier Waves (11 years' data).

Element.	c_2/c_1.				c_3/c_1.				c_4/c_1.			
	Year.	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.
H	0·54	0·94	0·52	0·40	0·25	0·56	0·30	0·12	0·12	0·27	0·14	0·06
V	0·65	0·46	0·70	0·68	0·24	0·23	0·32	0·19	0·09	0·11	0·13	0·04
T	0·61	0·83	0·63	0·53	0·21	0·43	0·28	0·11	0·07	0·15	0·10	0·03
N	0·52	0·63	0·49	0·47	0·18	0·33	0·22	0·07	0·07	0·11	0·08	0·04
W	0·65	0·53	0·73	0·61	0·32	0·27	0·42	0·25	0·12	0·18	0·18	0·04
I	0·51	0·65	0·48	0·41	0·30	0·42	0·35	0·19	0·16	0·24	0·18	0·09

TABLE XXVIII.—Amplitudes of Fourier Waves. (Unit 1γ.)

Element.	Period.	c_1.				c_2.				c_3.				c_4.			
		Year.	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.
H	Sunspot maximum	12·83	6·04	14·69	20·57	6·80	4·83	7·66	8·53	2·81	2·57	4·11	2·31	1·27	1·04	1·89	1·03
H	,, minimum	7·21	1·97	8·75	12·68	4·02	2·63	4·82	4·93	2·24	2·00	3·03	2·15	1·10	0·95	1·39	1·01
V	,, maximum	7·84	4·88	7·76	11·18	5·33	2·33	5·77	7·93	1·97	1·15	2·57	2·21	0·65	0·59	0·99	0·38
V	,, minimum	5·44	2·83	5·77	7·97	3·52	1·33	3·87	5·41	1·41	0·67	1·96	1·65	0·54	0·30	0·82	0·49

TABLE XXIX.—Ratios of Amplitudes of Fourier Waves.

Element.	Period.	c_2/c_1.				c_3/c_1.				c_4/c_1.			
		Year.	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.
H	Sunspot maximum . . .	0·53	0·80	0·52	0·41	0·22	0·43	0·28	0·11	0·10	0·17	0·13	0·05
H	,, minimum . . .	0·56	1·33	0·55	0·39	0·31	1·01	0·35	0·17	0·15	0·48	0·16	0·08
V	,, maximum . . .	0·54	0·48	0·74	0·71	0·25	0·24	0·33	0·20	0·08	0·12	0·13	0·03
V	,, minimum . . .	0·65	0·47	0·67	0·68	0·26	0·24	0·34	0·21	0·10	0·11	0·14	0·06

Table XXVIII. contrasts the sunspot maximum and minimum values of the amplitude for the year and seasons in both H and V. In H the sunspot maximum value of the amplitude is always the greater. Its excess, however, relatively considered, diminishes as the order of the harmonic increases, and except in c_2 it is least marked in summer.

In V the sunspot maximum value is also always the greater, except in the case of the summer value of c_4; but the pre-eminence of the sunspot maximum value is not specially conspicuous in c_1.

Table XXIX. contrasts the ratios borne to c_1 by c_2, c_3, and c_4 in the seasonal diurnal inequalities in the sunspot maximum and sunspot minimum groups of years. In the case of V the ratios seem little dependent on sunspot frequency, whereas in H with one exception they rise as sunspots diminish, especially in winter. In that season, in fact, in sunspot minimum the amplitude of the 24-hour term is exceeded by that of the 12-hour term and even by that of the 8-hour term.

§ 22. Table XXX. contrasts the phase angles in the diurnal inequalities for the year and seasons in the six elements H, V, T, N, W, and I. An increase in the phase angle as we pass from winter to equinox, and from equinox to summer, is shown by H, N, and T in all four Fourier waves. It is also shown by V in the case of α_4, and by W in the case of α_2. A fall as we pass from winter to equinox, and from equinox to summer, is shown by V in the case of α_1, α_2, and α_3, and by W in the case of α_1. T is remarkable for the smallness of the seasonal variation in the phase angles, especially in the case of α_2.

Table XXXI. contrasts the seasonal and yearly diurnal inequality phase angles in years of sunspot maximum and minimum. In the case of α_2 the sunspot minimum angle is invariably the greater for both H and V. The same is true of α_3, except in the case of H in equinox, when the sunspot minimum angle is slightly the smaller. The same rule is observed by α_4 in H, except in summer; but in V the sunspot maximum value of α_4 is the larger, though its excess is generally small. The sunspot maximum value of α_1 is the larger in summer and winter in H, and in all cases in V.

Table XXXII. shows the difference between the phase angles found in the present paper for ordinary days and those found in a previous paper* for quiet days. It gives the excess of the ordinary day over the quiet day phase angle converted into time at the rate of 1 hour = 15° in α_1, 30° in α_2, 45° in α_3, and 60° in α_4. The plus sign is equivalent to an earlier occurrence of phenomena in ordinary days. The values under the seasons, it should be noticed, are from the seasonal inequalities, and are not arithmetic means from the months included.

The outstanding feature is the preponderance of plus signs in the case of the 24-hour term in V, and the large size of most of the differences from this term.

* 'Phil. Trans.,' A, vol. 202, p. 335.

TABLE XXX.—Phase Angles Referred to Local Mean Time (11 years' data).

Element.	α_1.				α_2.				α_3.				α_4.			
	Year.	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	°	°	°	°	°	°	°	°
H	115 23	62 13	107 20	132 9	300 53	276 22	301 44	313 20	169·9	150·4	163·8	203·0	22·6	8·0	19·1	45·5
V	142 43	161 21	140 56	136 40	271 6	282 56	269 32	269 5	100·8	113·7	98·6	97·3	286·0	275·0	288·9	291·1
T	132 33	137 58	127 23	134 48	280 50	279 56	280 16	281 38	125·7	132·1	123·7	123·3	328·3	320·9	326·5	343·2
N	95 48	65 1	91 43	111 38	275 18	257 5	275 41	284 52	138·4	131·9	135·2	159·5	5·3	−15·9	−2·8	42·7
W	219 11	249 16	221 43	204 29	32 53	14 15	31 22	41 14	228·6	228·3	222·4	236·2	51·4	47·0	53·4	53·3
I	285 15	220 52	277 17	310 40	134 58	94 40	136 0	155 57	6·5	−22·8	−1·1	41·7	214·1	197·8	211·7	227·1

TABLE XXXI.—Phase Angles Referred to Local Mean Time.

Element.	Sunspot.	α_1.				α_2.				α_3.				α_4.			
		Year.	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.	Year.	Winter.	Equinox.	Summer.
		° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	°	°	°	°	°	°	°	°
H	Maximum . .	114 40	70 55	106 57	132 15	299 15	274 38	301 10	311 7	166·7	144·5	163·2	198·9	20·9	3·2	17·4	45·8
H	Minimum . .	117 31	48 19	108 57	131 53	306 36	286 40	303 15	320 25	173·9	155·1	162·7	208·5	24·4	14·3	19·3	41·3
V	Maximum . .	145 31	162 33	144 50	138 39	269 43	279 56	267 48	268 7	97·1	106·3	94·8	94·9	286·3	278·3	289·5	290·2
V	Minimum . .	137 59	159 18	132 24	134 39	273 42	286 30	271 7	272 26	104·9	124·4	101·2	101·5	283·6	278·2	282·2	289·1

There is obviously a considerable "accidental" element in the results for individual months, especially in the shorter period waves. There is, however, an unmistakable seasonal variation in the phenomena in the 24-hour term in H. In the summer months, the difference, though small, is clearly positive, whereas in winter it is not merely negative but very large, exceeding an hour of time. The fact is the seasonal variation in α_1 in H is much more pronounced in ordinary than in quiet days, the monthly values showing a range of 97° in the first case as compared with 71° in the second.

TABLE XXXII.—Ordinary less Quiet Day Phase Angle in Minutes of Time.

Month and season.	24-hour term.		12-hour term.		8-hour term.		6-hour term.	
	H.	V.	H.	V.	H.	V.	H.	V.
January	− 68	− 5	+ 8	− 38	− 4	+ 5	− 5	− 8
February	− 60	+ 16	− 1	− 23	− 4	+ 6	+ 6	+ 3
March	− 2	+ 95	+ 1	− 3	− 4	+ 2	− 2	− 4
April	+ 19	+ 76	+ 7	− 3	+ 3	+ 1	+ 13	+ 7
May	+ 8	+ 66	− 14	− 9	+ 5	− 1	+ 4	+ 14
June	+ 3	+ 48	− 9	− 3	+ 8	− 13	+ 24	+ 7
July	+ 12	+ 58	− 2	− 5	+ 15	− 1	+ 18	+ 10
August	+ 5	+ 60	+ 1	− 9	− 1	− 3	− 3	− 9
September	− 31	+ 100	− 25	− 9	− 14	− 2	+ 1	− 14
October	− 25	+ 112	+ 1	− 7	0	− 1	+ 4	+ 8
November	− 69	+ 55	− 7	− 26	− 4	+ 14	0	− 3
December	− 100	+ 67	− 1	− 64	− 5	+ 6	+ 14	− 17
Year	− 6·2	+ 72·2	− 3·0	− 9·7	− 5·3	+ 0·2	+ 3·8	+ 0·1
Winter	− 82·6	+ 29·8	− 1·8	− 15·8	− 4·5	+ 8·1	+ 2·2	− 4·8
Equinox	− 9·0	+ 94·9	− 3·4	− 5·5	− 4·7	0·0	+ 3·1	+ 0·1
Summer	+ 7·5	+ 58·7	− 6·4	− 6·7	+ 5·3	− 4·0	+ 4·8	+ 5·6

The differences in both α_1 and α_2 in V also show a decided seasonal variation. They are algebraically greater in summer than in winter; but in the case of α_1 the equinoctial values are the largest of all.

The variation of α_1 in V in the course of the year is only $42\frac{1}{2}°$ in ordinary as compared with $50\frac{1}{2}°$ in quiet days. The reduction in the annual range of α_2 in V on ordinary as compared with quiet days is fully larger.

As regards α_3 and α_4 the differences between the ordinary and quiet day phase angles are small, and in the case of V practically evanescent for the mean diurnal inequality of the year. There is an irregularity in the incidence of the plus and minus signs in the case of the α_4 differences which shows the advisability of reserve even as regards the seasonal figures. In the case of α_3 the plus and minus signs show a regular incidence, so that more reliance can be placed on the seasonal values. It will be noticed that the seasonal variations in the two elements are exactly opposite.

Before leaving the subject, attention may be called to the remarkable difference between the phenomena exhibited in the case of α_1 by the different elements. In D the ordinary day phase angle substantially exceeded the quiet day angle throughout the whole year, the excess being greatest in the equinoctial and least in the summer months. The excess in the mean diurnal inequality for the year represented about $29\frac{1}{2}$ minutes* of time. In H the ordinary day phase angle slightly exceeded the quiet day angle in summer, but fell notably short of it in winter, and in the diurnal inequality for the whole year was inferior to an extent representing about 6 minutes of time. In V the ordinary day phase angle substantially exceeded the quiet day angle throughout the year, the excess being greatest in the equinoctial and least in the winter months. In the mean diurnal inequality for the year the excess represented about 72 minutes of time.

WOLF'S *Formula*.

§ 23. If R denote the range of the mean diurnal inequality for the year, and S the sunspot frequency (after WOLF and WOLFER), the formula

$$R = a+b\,S = a\{1+(b/a)S\}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

with a and b constants, was found by Prof. WOLF to represent closely the variation of the declination range with sunspot frequency. It has been applied by myself to the ranges of the other magnetic elements, and to the individual months or seasons of the year as well as to the whole year. In the case of the quiet day inequalities, the formula applied fairly to all the magnetic elements, being as closely true of H as of D. The value of b/a was, however, not the same for the different elements. Also, when the 12 months were treated separately, b/a fluctuated from month to month, being greatest in winter and least in summer.

The formula has now been applied in the case of both H and V to the diurnal inequalities from ordinary days, for the year, the seasons, and the individual 12 months. The results appear in Table XXXIII.; 1γ is the unit in the case of a and b, and in the mean (numerical) difference between the values calculated by aid of the formula and those actually observed. While a and b are given respectively to 2 and to 4 places of decimals, so as to show the exact values employed in the calculated ranges, the last figure possesses little if any physical significance. Two sets of results are given for the year and the seasons. In the first set the values assigned to a and b are arithmetic means from the individual months included. The corresponding value given for b/a is derived from these mean values of a and b, and is not the arithmetic mean of the values of b/a for the individual months. The second set of figures refers to the diurnal inequalities calculated for the year and seasons.

* There is a mistake in the description of Table XII. of my previous paper dealing with the declination. The data in it refer not to the seasonal inequalities, but to arithmetic means from the individual months comprised in the season.

Taking, as an example, January in the case of H, the observed ranges in the Januarys of the 11 years were assumed to be given by a formula of type (1), S representing the mean sunspot frequency for each January in succession. The

TABLE XXXIII.—Constants in WOLF'S Formula $R = a+bS$.

Month and Season.	Horizontal force.					Vertical force.				
	a.	b.	$100\ b/a$.	Mean difference observed ∼ calculated.		a.	b.	$100\ b/a$.	Mean difference observed ∼ calculated.	
				Absolute value.	As percentage of range.				Absolute value.	As percentage of range.
	γ	γ		γ		γ	γ		γ	
January	11·12	0·1358	1·22	2·2	12·2	5·80	0·0666	1·15	0·8	13·6
February	12·13	0·1495	1·23	1·5	11·4	9·43	0·1060	1·12	1·8	17·1
March	18·31	0·2674	1·46	2·4	12·9	19·26	0·1169	0·61	2·2	16·4
April	26·83	0·2946	1·10	3·0	12·6	25·45	0·0693	0·27	1·9	15·8
May	30·38	0·2232	0·74	3·8	11·7	27·74	0·1438	0·52	1·6	9·4
June	32·29	0·2561	0·79	3·0	12·1	25·12	0·1213	0·48	1·4	11·2
July	32·43	0·2450	0·75	4·3	14·6	24·56	0·1461	0·59	1·9	12·1
August	32·35	0·1825	0·56	4·2	16·7	23·28	0·0487	0·21	2·2	22·2
September	26·71	0·1831	0·69	3·1	16·4	16·73	0·1287	0·77	2·0	16·2
October	19·32	0·2635	1·36	2·2	11·2	12·16	0·1271	1·05	1·6	12·6
November	12·05	0·2195	1·82	2·3	12·3	8·63	0·0942	1·09	1·5	14·7
December	9·67	0·1079	1·12	2·2	15·4	4·99	0·0712	1·43	1·2	12·6
From a.m.s. of a's and b's—										
Year	21·97	0·2107	0·96	2·8	13·3	16·93	0·1033	0·61	1·7	14·5
Winter	11·24	0·1532	1·36	2·0	12·8	7·21	0·0845	1·17	1·3	14·5
Equinox	22·79	0·2522	1·11	2·7	13·3	18·40	0·1105	0·60	1·9	15·2
Summer	31·86	0·2267	0·71	3·8	13·8	25·18	0·1150	0·46	1·8	13·7
From seasonal inequalities—										
Year	18·20	0·2081	1·14	0·5	3·3	16·17	0·1044	0·65	0·8	8·5
Winter	10·78	0·1544	1·43	0·7	6·1	6·79	0·0812	1·20	0·5	6·9
Equinox	20·81	0·2588	1·24	1·2	6·6	17·87	0·1085	0·61	1·4	15·1
Summer	30·95	0·2417	0·78	1·5	6·1	24·58	0·1198	0·49	1·3	9·9

appropriate values of a and b were then determined by least squares, and proved to be $a = 11{\cdot}12\gamma$, $b = 0{\cdot}1358\gamma$. Inserting these values of a and b in the formula, and ascribing to S in succession the frequencies of the 11 Januarys, values were deduced for R. The observed values of R in January fluctuated from $8{\cdot}1\gamma$ in 1899 to $25{\cdot}8\gamma$ in 1892, *i.e.*, they had a range of $17{\cdot}7\gamma$. The sum of the eleven differences between observed and calculated values taken irrespective of sign was $23{\cdot}7\gamma$, the mean difference

being thus 23·7/11 or 2·2γ. This expressed as a percentage of the range is 23·7 × 100/11 × 17·7, or 12·2.

There is obviously a good deal that is "accidental" in the results obtained for individual months, especially in V. The values of b/a, it will be seen, are decidedly larger for H than for V, implying that relatively considered the sunspot influence has more effect on the range of the former element than on that of the latter.

The differences between observed and calculated values naturally tend to increase in size with the extent of the variation of R during the 11 years, and so are largest in summer. The fairest way, however, to compare the accuracy of the formula at different seasons, or for different elements, is to take as criterion the percentage which the mean difference between observed and calculated values is of the difference between the largest and least observed values of R. In H these percentages show no marked variation with the season. There are considerably greater variations in V, but they probably represent in the main the smaller accuracy of observed values in that element, as the largest and smallest values for individual months both fall in summer.

If we exclude the equinoctial value in V, the agreement between observed and calculated values is decidedly closer for the seasons than for individual months, and in the case of H it is still closer, to a marked degree, for the year.

One's estimate of the suitability of a formula, while mainly determined by the size of the mean difference between observed and calculated values, is partly determined by the mode of grouping of the plus and minus signs. For instance, if the plus signs all occurred together, there would be reason to suspect a sensible secular change in the amplitude of the diurnal inequality, quite apart from sunspot variation. Table XXXIV. accordingly records for each year the actual differences between the observed

TABLE XXXIV.—Observed less Calculated Ranges in mean Diurnal Inequality for the Year.

Element.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.
H	+0·1γ	+0·6γ	+0·5γ	−0·3γ	+0·4γ	−0·5γ	−0·1γ	0·0γ	−1·4γ	+1·3γ	−0·6γ
V	−1·7γ	+1·2γ	0·0γ	−1·6γ	+0·4γ	0·0γ	+1·0γ	+0·8γ	+1·1γ	0·0γ	−1·1γ
I	+0′·05	+0′·05	+0′·08	+0′·01	0′·00	−0′·06	−0′·07	−0′·04	−0′·13	+0′·13	−0′·03

and calculated values. The calculated values for H and V were derived from the values of a and b assigned in Table XXXIII. to the mean diurnal inequality for the year. The results for I were calculated from

$$a = 0'\cdot8648, \qquad b = 0'\cdot01111,$$

these being the values obtained by the aid of least squares from the observed I range, in the mean diurnal inequalities for the eleven years. The corresponding value of

$100b/a$, viz., 1·28, it may be pointed out, is considerably in excess even of that found for H, and double that found for V. An analogous result was observed in the case of the quiet day ranges.

The plus and minus signs occur pretty promiscuously in Table XXXIV. Also there seems no parallelism between the differences observed in the case of the different elements. In short the differences do not suggest anything but accident. Considering that the observed H ranges varied from $19{\cdot}6\gamma$ to $35{\cdot}6\gamma$, it seems not a little remarkable that in seven years out of the eleven, the difference between the observed and calculated value did not exceed $0{\cdot}5\gamma$. The mean difference between observed and calculated values of I was 0'·059, or 6·7 per cent. of the range in I during the eleven years. The agreement is thus closer than in the case of V, though decidedly less good than in the case of H.

§ 24. WOLF's formula was also applied to the observed amplitudes of the 24-, 12-, 8- and 6-hour terms in the mean diurnal inequality for the whole year, in the case of H and V. The results appear in Table XXXV. The agreement between the observed and calculated values is in general good, especially in the case of the 24- and 12-hour terms in H and the 12-hour term in V. It is least good in the case of the 6-hour terms, whose amplitudes even at their largest are very small. The general tendency apparently is for b/a to become smaller, *i.e.*, for the sunspot influence to be less marked, as the order of the harmonic increases, but the 24-hour term in V seems exceptional.

TABLE XXXV.—Constants in WOLF's Formula $R = a+bS$.

	Horizontal force.					Vertical force.				
	a.	b.	$100\,b/a$.	Mean difference observed∼calculated. Absolute value.	Mean difference observed∼calculated. As percentage of range.	a.	b.	$100\,b/a$.	Mean difference observed∼calculated. Absolute value.	Mean difference observed∼calculated. As percentage of range.
	γ	γ		γ		γ	γ		γ	
c_1	6·32	0·0868	1·37	0·27	4·1	5·62	0·0317	0·56	0·40	12·1
c_2	3·49	0·0440	1·26	0·21	6·0	3·42	0·0260	0·76	0·15	7·0
c_3	2·04	0·0103	0·51	0·14	10·5	1·32	0·0090	0·68	0·10	10·0
c_4	1·05	0·0028	0·27	0·04	12·1	0·49	0·0023	0·47	0·05	22·7

The values obtained for a, b, and b/a for ordinary days in the case of H are very similar to those obtained from the quiet day ranges, but are on the whole slightly larger. In the case of V the differences between ordinary and quiet day results are more marked, and the excess in the b/a from ordinary days over that for quiet days is larger.

Daily Range.

§ 25. The term daily or diurnal range is used in several senses. It may mean the difference R between the algebraically largest and least hourly values in the diurnal inequality, that inequality being derived from selected days or from all days. It may mean, however, the difference R′ between the highest and lowest daily values, irrespective of the time at which they occur, whether an exact hour or not. The mean R′ for a month is simply the arithmetic mean of the values for individual days of the month.

Tables XXXVI. and XXXVII. give R for H and V from ordinary days, for each month of the eleven years. Tables XXXVIII. and XXXIX. give R′ from all days for the same two elements. The R derived from any combination of days must be less than the corresponding R′, unless the maximum and minimum each occur at a fixed time, which is an exact hour. In practice, the times of the maximum and minimum vary from day to day. Speaking generally, the difference between R and R′ for a particular month is larger the more disturbed the month.

If instead of the month one takes the year, the mean R′ is the arithmetic mean of the values for the 12 months, but R is less than the arithmetic mean of the monthly values unless the hours of maximum and minimum in the inequality are the same throughout the year, which is never the case at Kew. Even when one considers the months of the same name from a number of years, there is usually some variation in the hour of maximum or minimum. To bring out these points, Tables XXXVI. and XXXVII. contain the values of R from the inequalities for the whole year and for all the months of the same name combined, as well as the arithmetic means of the values for the individual months.

In Table XXXVI., November is the only month in which the R from the months combined equals the arithmetic mean of the values for the separate months. In the other 11 months the former quantity is the smaller, though the difference is never large. There is a much larger difference between the inequality range for the whole year and the arithmetic mean of the values of R for the twelve months. The former quantity on the average stands to the latter approximately in the ratio 7 : 8.

In Table XXXVII., April is the only month in which R from all the months combined is the same as the arithmetic mean of the values for the individual months, but the differences in the other months are small, just as in the case of H. The differences in Table XXXVII. between the inequality range for the year and the arithmetic mean of the ranges for the twelve months are a good deal smaller than in the case of H. The average excess of the arithmetic means is only about $3\frac{1}{2}$ per cent. This implies, of course, less variability in the hours of maximum and minimum.

Comparing Tables XXXVIII. and XXXIX. with Tables XXXVI. and XXXVII. we see that the excess of R′ over R is usually large. Allowance must, of course, be made for the fact that the more highly disturbed days—242 for H and 348 for V—

TABLE XXXVI.—Horizontal Force. All Ordinary Days. Inequality Ranges. (Unit 1γ.)

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Arithmetic mean.	Inequality for year.
1890	11·9	14·9	20·6	28·7	25·6	33·3	33·5	31·9	30·3	23·3	15·6	13·9	23·6	19·8
1891	13·1	14·0	22·7	35·5	34·5	39·8	44·2	43·0	39·2	38·0	26·2	16·2	30·5	26·2
1892	25·8	25·1	35·2	45·5	45·1	48·4	58·2	55·4	36·3	41·6	24·3	14·3	37·9	33·9
1893	17·8	22·8	36·5	51·0	46·5	57·6	57·2	51·9	43·8	40·7	30·2	23·0	39·9	35·6
1894	21·7	24·7	31·6	49·6	58·0	57·9	50·8	52·2	41·2	37·8	23·4	18·7	39·0	34·8
1895	18·1	23·0	38·0	50·7	45·2	56·5	52·5	37·3	33·9	33·1	24·2	16·7	35·8	31·0
1896	19·1	21·5	29·8	44·5	40·7	38·9	40·0	42·3	40·3	25·6	15·0	9·8	30·6	26·8
1897	17·9	17·6	25·9	42·7	40·8	37·7	36·7	33·1	28·8	24·2	12·4	12·4	27·5	23·6
1898	14·9	12·2	22·2	26·9	36·0	41·9	39·0	34·7	31·3	23·7	17·8	9·9	25·9	22·4
1899	8·1	14·6	19·8	28·1	37·7	38·1	36·8	34·8	34·9	22·2	16·7	10·7	25·2	22·0
1900	13·5	13·3	23·5	26·8	30·1	33·1	28·7	30·3	24·7	23·4	11·3	8·5	22·3	19·6
Arithmetic mean . .	16·5	18·5	27·8	39·1	40·0	43·9	43·4	40·6	35·0	30·3	19·7	14·0	30·7	26·9
11-year inequality .	16·0	18·1	26·7	38·3	39·9	43·8	43·1	40·2	34·5	29·9	19·7	13·6	—	—

TABLE XXXVII.—Vertical Force. All Ordinary Days. Inequality Ranges. (Unit 1γ.)

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Arithmetic mean.	Inequality for year.
1890	5·7	11·3	19·0	24·2	25·5	24·2	25·3	18·8	17·0	9·2	5·6	3·1	15·7	15·2
1891	6·2	8·3	23·7	28·6	32·8	30·2	34·0	28·9	23·3	21·2	13·7	10·0	21·7	21·1
1892	11·7	16·6	30·8	27·8	40·3	33·1	36·2	28·2	23·8	22·0	12·1	10·7	24·4	23·8
1893	10·9	14·3	22·0	30·6	37·1	36·3	39·2	27·0	28·3	20·9	15·6	12·9	24·6	23·4
1894	10·3	18·2	24·6	33·2	42·2	36·1	36·8	28·8	28·5	21·2	15·8	9·0	25·4	24·7
1895	10·2	18·9	26·6	30·5	39·0	36·2	36·3	25·8	18·7	20·0	15·2	8·4	23·8	22·8
1896	10·2	17·5	27·8	29·3	31·9	31·0	30·6	27·6	24·7	17·2	10·6	7·7	22·2	21·5
1897	7·5	14·4	23·4	29·9	33·5	28·0	25·8	26·0	22·3	16·0	10·5	5·2	20·2	19·7
1898	6·2	15·3	21·9	27·8	33·6	30·8	28·7	26·4	24·3	16·1	11·8	6·0	20·7	20·1
1899	6·8	9·6	20·6	28·5	29·5	25·1	26·0	20·6	20·6	12·5	10·7	7·9	18·2	17·4
1900	7·2	9·1	17·1	21·2	27·9	25·9	23·3	22·3	16·4	15·8	9·6	5·5	16·8	16·1
Arithmetic mean .	8·4	14·0	23·4	28·3	33·9	30·6	31·1	25·5	22·5	17·5	11·9	7·9	21·2	20·5
11-year inequality .	7·9	13·8	23·0	28·3	33·6	30·4	30·9	25·3	22·1	17·0	11·5	7·1	—	—

contributed to R′ but not to R. If they had been excluded in both cases, R′ would have been appreciably reduced, more especially in the equinoctial months and in the

TABLE XXXVIII.—Horizontal Force. All Days. Absolute Ranges. (Unit 1γ.)

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Mean.
1890	35·1	43·1	39·6	46·3	40·3	47·4	50·5	52·6	55·8	54·1	41·8	31·4	44·8
1891	34·9	47·4	66·8	74·6	75·9	60·0	61·4	69·3	74·3	71·4	50·7	43·0	60·8
1892	56·2	113·0	114·1	83·9	91·2	83·1	117·3	96·1	70·6	74·6	54·9	53·4	84·0
1893	55·4	59·1	67·6	77·5	65·3	85·7	83·1	88·5	79·8	71·5	60·4	43·1	69·7
1894	61·6	98·5	78·3	78·8	82·8	95·0	106·4	95·1	88·6	71·9	74·2	46·2	81·4
1895	47·4	66·0	75·6	81·3	76·2	82·3	80·5	58·0	62·7	73·3	64·4	46·5	67·9
1896	63·5	68·2	68·5	74·4	78·7	60·5	68·0	75·7	76·9	58·1	43·1	38·9	64·5
1897	40·0	41·8	51·8	77·6	68·9	55·6	53·9	51·2	48·3	50·7	37·8	44·1	51·8
1898	39·4	49·0	73·1	51·7	64·6	62·3	60·3	61·7	77·0	54·8	40·0	37·8	56·0
1899	39·3	42·1	50·4	55·9	64·7	60·5	55·0	57·1	59·9	41·7	33·6	35·0	49·6
1900	39·1	33·4	47·8	41·4	48·6	43·5	40·2	42·6	36·1	34·7	22·7	18·1	37·3
Mean .	46·5	60·1	66·7	67·6	68·8	66·9	70·6	68·0	66·4	59·7	47·6	39·8	60·7

years 1892, 1894, and 1896; while, if they had been included in both cases, R would probably have been slightly increased.

TABLE XXXIX.—Vertical Force. All Days. Absolute Ranges. (Unit 1γ.)

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Mean.
1890	16·6	20·6	26·5	27·2	28·4	26·8	25·8	23·0	21·9	22·0	15·5	3·6	21·5
1891	15·5	23·9	35·9	42·8	53·7	31·6	35·8	33·5	47·3	32·2	25·5	24·8	33·5
1892	25·0	65·8	74·9	49·0	68·4	52·2	68·0	48·3	33·0	39·9	28·3	32·8	48·8
1893	27·0	33·1	34·1	35·3	38·6	44·0	44·7	46·9	39·9	34·6	37·4	24·4	36·7
1894	28·8	68·6	52·8	45·7	44·9	45·9	65·8	48·7	58·0	29·1	45·8	21·8	46·3
1895	23·8	38·8	38·9	40·8	44·0	43·3	38·6	30·8	30·7	40·6	32·6	24·0	35·6
1896	28·8	34·7	44·8	37·8	51·7	32·4	36·2	37·2	32·7	30·0	22·6	22·3	34·3
1897	23·5	21·2	28·9	44·1	37·9	29·4	28·0	27·8	23·8	20·7	16·6	19·3	26·8
1898	17·2	26·1	53·3	30·8	36·4	30·8	29·3	33·0	44·1	27·6	22·9	18·0	30·8
1899	21·1	25·5	29·2	31·7	33·0	33·2	29·2	24·6	24·3	17·7	14·9	17·4	25·1
1900	19·0	16·8	27·0	23·4	34·8	26·8	25·8	26·0	19·3	19·7	13·9	12·8	22·1
Mean	22·4	34·1	40·6	37·1	42·9	36·0	38·8	34·5	34·1	28·6	25·1	20·1	32·9

§ 26. Table XL. gives the ratio borne by the mean R′ to the corresponding arithmetic mean of the values of R for the 12 months and for the 11 years separately. The disturbed days omitted from the V inequalities were the more numerous, so that any reduction in R consequent on this exclusion would naturally be greater in V than in H. The excess of R′ is, however, invariably much larger for H than for V, confirmatory of what has been already said as to the former being in general much the more disturbed element. Relatively considered, the excess of R′ over R has a conspicuous maximum near mid-winter, and a minimum near mid-summer. The pre-eminence of the values of R′/R in winter over those in equinoctial months is hardly what one would have expected from consideration of disturbances alone. We see that the size of the regular diurnal inequality is apt to give in winter a very inadequate idea of the average diurnal variation in the field.

TABLE XL.—Values of (Absolute Range from All Days)/(Inequality Range from Ordinary Days).

Element.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Mean.
H	2·81	3·25	2·40	1·73	1·72	1·52	1·63	1·67	1·90	1·97	2·41	2·84	2·13
V	2·65	2·44	1·73	1·31	1·26	1·18	1·25	1·35	1·51	1·64	2·10	2·56	1·75

	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.
H	1·90	1·99	2·22	1·74	2·09	1·90	2·11	1·88	2·16	1·97	1·67	1·97
V	1·37	1·54	2·00	1·49	1·82	1·49	1·55	1·32	1·49	1·38	1·32	1·52

If we compare the values of R′/R in different years, we see that while on the whole it was least in the years of fewest sunspots, it was considerably below average in 1893, the year of sunspot maximum. In the case of H, in fact, it was lower for 1893 than for any other year except 1900. This means that in 1893 R was specially large, and not that R′ was small. As Table XXXVIII. shows, the mean value of R′ for 1893 was 15 per cent. above the average of the 11 years, and was exceeded only in 1892 and 1894. In the case of V the value of R′/R for 1893, though less remarkable, was below the mean. In both H and V the values of R′ for 1892 and 1894 were much in excess of that for 1893. For 1892 this excess was 21 per cent. for H, and 33 per cent. for V.

Table XLI. shows the order in which the years stand when placed in descending order of range. Data for D are included to make the survey more complete. The

resulting order is also shown when the figures from D, H and V are added, and finally the order when the sunspot frequency is the criterion. R and R′ are treated separately.

When the size of R′ is the criterion, the order is the same for all the magnetic elements, except that 1890 comes last in V, while 1900 comes last in D and H.

There is less agreement between the results from the three elements in the case of R, but the differences between the pairs of years 1890 and 1900, 1892 and 1894, and last 1897 and 1898, are so small that little significance attaches to the precise order in which the members of the pair present themselves. In the final returns from the three elements combined, the only difference between the R and R′ lists is that there is an interchange of place between 1892 and 1893, and between 1897 and 1898.

Table XLI.—Position of Years when Arranged in Descending Order of R, R′, and S.

		1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.
R	D	9	6	2	1	3	4	5	7	8	10	11
	H	10	6	3	1	2	4	5	7	8	9	11
	V	11	6	3	2	1	4	5	8	7	9	10
	Mean . .	10	6	3	1	2	4	5	7	8	9	11
R′	D	10	6	1	3	2	4	5	8	7	9	11
	H	10	6	1	3	2	4	5	8	7	9	11
	V	11	6	1	3	2	4	5	8	7	9	10
	Mean . .	10	6	1	3	2	4	5	8	7	9	11
Sunspots		11	6	3	1	2	4	5	8	7	9	10

Table XLII. deals with the twelve months in the same way that Table XLI. dealt with the eleven years. In Table XLII. the points of agreement between the different elements in the same list, or between the same element in the two lists, are somewhat inconspicuous outside the mid-winter months. Successive months sometimes occupy very different positions, without there being a very large difference between their values of the ranges. A longer period of years would be required to eliminate satisfactorily what is accidental. Whether one takes R or R′, it is clear that December, January, and November fill the last three places.

When the three elements are combined, May, July, and August are bracketed second in the case of R. In the case of R′ there is a bracket between April and July, and again between June and September.

The difference between the positions occupied by June in the R and R′ lists is remarkable. In the R list it comes first, slightly in advance of the other three mid-summer months, whereas in the R′ list no element places it higher than fifth.

Another striking phenomenon is the difference between the positions assigned to March and July in the R′ list according as the element considered is D or H. In the case of H, it is true, the mean values of R′ for the six months March to September differ comparatively little. Still the fact that (July Range/March Range) = 0·88 for D, but = 1·06 for H, appears a little remarkable.

TABLE XLII.—Position of Months when Arranged in Descending Order of R and R′.

		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
R	D	11	9	7	2	4	3	5	1	6	8	10	12
	H	11	10	8	5	4	1	2	3	6	7	9	12
	V	11	9	6	4	1	3	2	5	7	8	10	12
	Mean .	11	9	7	5	(2)	1	(2)	(2)	6	8	10	12
R′	D	11	8	1	2	3	9	6	5	4	7	10	12
	H	11	8	6	4	2	5	1	3	7	9	10	12
	V	11	7	2	4	1	5	3	6	8	9	10	12
	Mean .	11	8	2	(3)	1	(6)	(3)	5	(6)	9	10	12

§ 27. In the case of the mean diurnal inequality for the year there is, as we have seen, a close connection between the range and the corresponding sunspot frequency S. This does not necessarily imply any close connection between sunspot frequency on any given day and the amplitude of the regular or irregular magnetic changes on the same day. It seems increasingly difficult to think of any cause for the magnetic diurnal inequality other than electrical currents in the upper atmosphere. In temperate latitudes, whether at sunspot maximum or minimum, regular magnetic changes are most rapid during the day, but the difference between day and night seems reduced at sunspot maximum. Whether by day or by night, the regular changes are larger in sunspot maximum than in sunspot minimum. The most natural inference is that direct sunlight, whether there are or are not sunspots, increases the conductivity of the upper atmosphere, and that the effect persists to some extent during the night. At sunspot maximum the upper atmosphere is more conducting than at sunspot minimum at the same hour. The state of the upper atmosphere as regards

conductivity may be due to contributions from some, perhaps many, previous days. The solar influences may be of different kinds, taking different times to travel from the sun and decaying at different rates. Sunspots again may be evidence of some effect on the sun which is shared by the solar system, but which takes some time to travel the distance separating the earth from the sun. The diurnal inequality can be derived only from a combination of days. Thus it does not enable us to compare magnetic conditions and sunspot frequency on individual days. There is even a difficulty in comparing the run of magnetic conditions and sunspots during successive months, owing to the annual variation in the daily range. This difficulty can, however, be fairly surmounted if we express the range for each month as a percentage of the mean range from all months of the same name in the 11-year period. The percentage values thus obtained for R and R′ in H appear in Table XLIII. along with the corresponding WOLFER's sunspot frequency, the latter in heavy type.

The general tendency for the percentage figures in Table XLIII. to be large in years of many, and small in years of few sunspots, is of course obvious. But when we compare successive months, we see that with rise of S we may have rise or fall of R, and that R and R′ not infrequently change in opposite directions. There being 132 months, there are 131 passages from one month to the next. If we allow 1/2 in cases where the value is the same in two consecutive months, we find that R and R′ changed in the same direction in 84 cases, S and R changed in the same direction in $65\frac{1}{2}$ cases, while S and R′ changed in the same direction in $72\frac{1}{2}$ cases. A large monthly value for R′ may be due to only two or three highly disturbed days, excluded from the ordinary days, still the number of cases in which R and R′ changed in opposite direction is larger than would have been expected. The figures quoted above, by themselves, afford no evidence of a connection between S and R in individual months, and only slight evidence of a connection between S and R′. This differs from what was observed in the case of D. There R and S increased or diminished together in 75 cases out of 131, while R′ and S increased or diminished together only in 68 cases.

In many instances the values of S for consecutive months differ so little that accident might play a considerable part. If we confine ourselves to the 52 cases in which S changed by at least 10 units, there was agreement in the direction of change

in 30 cases as between R and S,
,, 28 ,, ,, R′ ,, S,
,, 34 ,, ,, R ,, R′.

This is decidedly more favourable to a connection between R and S in individual months.

In a second investigation the months of each year were arranged in two groups of 6, consisting respectively of the months of largest and least sunspot frequency. The

TABLE XLIII.—Comparison of Sunspot Frequencies and H Range Percentages.

Year.		January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
1890	S	**5·3**	**0·6**	**5·1**	**1·6**	**4·8**	**1·3**	**11·6**	**8·5**	**17·2**	**11·2**	**9·6**	**7·8**
	R	72	80	74	73	64	76	77	79	87	77	79	99
	R′	75	72	59	68	59	71	72	77	84	91	88	79
1891	S	**13·5**	**22·2**	**10·4**	**20·5**	**41·1**	**48·3**	**58·8**	**33·2**	**53·8**	**51·5**	**41·9**	**32·2**
	R	79	76	82	91	86	91	102	106	112	125	133	116
	R′	75	79	100	110	110	90	87	102	112	120	107	108
1892	S	**69·1**	**75·6**	**49·9**	**69·6**	**79·6**	**76·3**	**76·8**	**101·4**	**62·8**	**70·5**	**65·4**	**78·6**
	R	157	136	127	116	113	110	134	136	104	137	123	102
	R′	121	188	171	124	133	124	166	141	106	125	115	134
1893	S	**75·0**	**73·0**	**65·7**	**88·1**	**84·7**	**88·2**	**88·8**	**129·2**	**77·9**	**79·7**	**75·1**	**93·8**
	R	108	123	131	130	116	131	132	128	125	134	153	164
	R′	119	98	101	115	95	128	118	130	120	120	127	108
1894	S	**83·2**	**84·6**	**52·3**	**81·6**	**101·2**	**98·9**	**106·0**	**70·3**	**65·9**	**75·5**	**56·6**	**60·0**
	R	131	134	114	127	145	132	117	129	118	125	119	134
	R′	132	164	117	117	120	142	151	140	133	120	156	116
1895	S	**63·3**	**67·2**	**61·0**	**76·9**	**67·5**	**71·5**	**47·8**	**68·9**	**57·7**	**67·9**	**47·2**	**70·7**
	R	110	124	137	130	113	129	121	92	97	109	123	119
	R′	102	110	113	120	111	123	114	85	94	123	135	117
1896	S	**29·0**	**57·4**	**52·0**	**43·8**	**27·7**	**49·0**	**45·0**	**27·2**	**61·3**	**28·4**	**38·0**	**42·6**
	R	116	116	107	114	102	89	92	104	115	84	76	70
	R′	137	114	103	110	114	90	96	111	116	97	90	98
1897	S	**40·6**	**29·4**	**29·1**	**31·0**	**20·0**	**11·3**	**27·6**	**21·8**	**48·1**	**14·3**	**8·4**	**33·3**
	R	108	95	93	109	102	86	85	82	82	80	63	89
	R′	86	70	78	115	100	83	76	75	73	85	79	111
1898	S	**30·2**	**36·4**	**38·3**	**14·5**	**25·8**	**22·3**	**9·0**	**31·4**	**34·8**	**34·4**	**30·9**	**12·6**
	R	90	66	80	69	90	95	90	85	89	78	90	71
	R′	85	81	110	77	94	93	85	91	116	92	84	95
1899	S	**19·5**	**9·2**	**18·1**	**14·2**	**7·7**	**20·5**	**13·5**	**2·9**	**8·4**	**13·0**	**7·8**	**10·5**
	R	49	79	71	72	94	87	85	86	100	73	85	76
	R′	85	70	76	83	94	90	78	84	90	70	71	88
1900	S	**9·4**	**13·6**	**8·6**	**16·0**	**15·2**	**12·1**	**8·3**	**4·3**	**8·3**	**12·9**	**4·5**	**0·3**
	R	82	72	85	69	75	75	66	75	71	77	57	61
	R′	84	56	72	61	71	65	57	63	54	58	48	46

mean values obtained for S and for the percentage values of R and R′ in H for the two groups appear in Table XLIV.

TABLE XLIV.—Percentage H Ranges from Groups of Months of Larger and Smaller Sunspot Frequency.

Year.	Group of months of largest sunspot frequency.			Group of months of least sunspot frequency.		
	S.	R per cent.	R′ per cent.	S.	R per cent.	R′ per cent.
1890	11·0	83	82	3·1	73	67
1891	49·2	108	104	22·0	92	96
1892	81·4	122	148	64·6	127	127
1893	95·5	133	116	74·4	129	114
1894	92·6	131	138	63·4	123	130
1895	70·6	115	113	57·4	119	111
1896	51·4	106	105	32·2	92	108
1897	35·3	96	89	17·2	83	83
1898	34·4	81	96	19·1	84	88
1899	16·5	73	80	7·7	87	83
1900	13·2	75	66	5·7	69	57
Mean . . .	50·1	102·1	103·4	33·3	98·0	96·7

The higher R′ percentage appears in the group of higher values of S in 9 years out of the 11. In the two exceptional years, 1896 and 1899, the deficiency in the value of R′ in the first group is only 3, and so possesses little significance. On the average of the eleven years, the excess of the percentage values of R′ in the first group amounts to 6·7. If we regard this as a percentage on $60{\cdot}7\gamma$, the mean value of R in H for the eleven years, we get $4{\cdot}0_7\gamma$ as corresponding to a difference of 16·8 in S. On a formula of the type $R' = a+b$ S, this would give

$$100\ b/a = 0{\cdot}47.$$

In the case of R the higher percentage value is associated with the higher value of S in 7 years. In one of the 4 exceptional years, 1899, the deficiency in R is substantial, but this possesses less significance than would otherwise be the case from the fact that the difference between the values of S for the two groups in that year is little over half the average. The excess in the percentage value of R in the group of higher values of S, on the average of the 11 years, is 4 1. If we regard this as a percentage on $30{\cdot}7\gamma$, the mean value of R in H from the 132 months, we get $1{\cdot}26\gamma$ as corresponding to a difference of 16·8 in S. On a formula of the type $R = a+b$ S, this would give

$$100\ b/a = 0{\cdot}27.$$

Taking the arithmetic mean of the monthly values of R in H for each year of the eleven, and applying the $R = a+b\,S$ formula, I found by least squares

$$a = 21{\cdot}47\gamma, \quad b = 0{\cdot}2224\gamma, \quad 100\; b/a = 1{\cdot}036.$$

The division of the year into equal groups of 6 months only partly attains the object in view, viz., the elimination of any cause whose effect lasts for several months, because there is some tendency for the months of higher S in a year to occur together. In 1890, for instance, the 6 months of largest S came from the second half of the year, while in 1894 and 1900 the first half of the year contributed 5 out of the 6 months in the first group. Taking this into account, and the smallness of the value of b/a deduced in the case of R from Table XLIV., the natural inference would seem to be that the value of R from ordinary days in a particular month depends less on the value of S in that month than on the values of S in the other months of the year.

This may mean nothing more than that the value of S on a particular day is a very rough measure of the solar activity to which enhanced diurnal inequalities are due, while the mean value of S from all days of the year affords a very exact measure.

The fact that the value of b/a derived from Table XLIV. in the case of R′ is so much larger than that derived in the case of R, suggests that the solar influence is more direct or immediate in the case of irregular than in the case of regular magnetic changes.

Table XLV. shows the result of grouping the 132 months according to the monthly mean value of S. Notwithstanding the considerable number of months included in the groups, the results of the first grouping in which the step in S is only 10 are somewhat irregular. R and R′ show a decided tendency throughout to increase with

TABLE XLV.—Percentage Ranges from Months Grouped according to Sunspot Frequency.

Range of values of S.	Months in group.	Mean values.			Range of values of S.	Months in group.	Mean values.		
		S.	R per cent.	R′ per cent.			S.	R per cent.	R′ per cent.
0 to 10	23	6·2	77·8	71·5	0 to 20	43	9·6	76·6	74·4
10 „ 20	20	13·8	75·1	77·7	20 „ 40	26	29·1	91·4	96·5
20 „ 30	14	25·1	93·0	94·6	40 „ 60	20	49·3	106·4	109·2
30 „ 40	12	33·7	89·5	98·7	60 „ 80	30	70·6	123·0	121·7
40 „ 50	12	45·4	103·0	106·7	>80	13	94·6	132·5	127·8
50 „ 60	8	55·0	111·5	112·9					
60 „ 70	14	65·4	120·2	112·6					
70 „ 80	16	75·2	125·4	129·6					
80 „ 90	7	85·6	128·7	124·1					
>90	6	105·1	137·0	132·0					

S, but in the group or groups with S above 80 the rate of increase seems reduced. The exceptionally high monthly values of S occurred sporadically. For instance, the extreme value, 129·2 in August 1893, was preceded by 88·8 in July and followed by 77·9 in September. Thus we should not expect a correspondingly high value of R unless the influence of previous months is negligible.

In considering the significance of Table XLV. allowance should be made for the fact that some of the groups come entirely from years of sunspot maximum. No value of S as high as 60 occurred in the sunspot minimum or intermediate years. Again, sunspot minimum years gave no value of S larger than 20·5, and so their contributions were practically confined to the groups 0 to 10 and 10 to 20. Intermediate years contributed only two months to the group 0 to 10, and six to the group 10 to 20.

§ 28. We have hitherto considered only mean monthly values of R′, but the way in which these values are made up seems also of interest. To make the results more complete, D has been included in the investigation. Some data for D were got out in a previous paper,* but they are considerably extended here. As a preliminary it is well to know something about the extreme values of R′. To this end Tables XLVI. and XLVII. give the smallest recorded values of R′ in D and H for each month.

TABLE XLVI.—Declination. Absolute Daily Ranges. Smallest Values.

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
	′	′	′	′	′	′	′	′	′	′	′	′	′
1890	4·2	5·6	5·1	8·2	6·2	6·9	8·0	8·2	5·0	5·7	5·0	3·8	3·8
1891	3·1	4·1	4·3	8·1	8·5	7·9	8·6	9·2	9·8	7·9	7·1	4·7	3·1
1892	5·7	8·3	11·4	10·9	10·3	9·2	11·4	10·1	9·2	8·5	3·7	5·7	3·7
1893	5·0	5·0	8·0	12·5	11·9	12·3	11·6	11·5	10·1	9·3	5·9	4·1	4·1
1894	6·8	7·9	8·3	9·6	10·6	10·5	6·8	9·7	10·3	9·0	4·7	4·6	4·6
1895	3·9	6·8	8·3	11·9	10·0	13·0	10·8	8·0	8·5	8·6	5·2	3·8	3·8
1896	6·0	7·3	8·0	10·9	9·0	6·7	7·9	9·8	8·2	6·6	3·4	2·7	2·7
1897	3·2	4·3	8·9	8·3	7·4	7·8	8·0	9·1	6·1	5·8	4·3	2·2	2·2
1898	3·1	3·5	6·0	8·0	7·1	7·7	7·2	8·0	7·5	6·5	4·3	3·3	3·1
1899	3·0	3·8	6·3	7·9	7·1	8·4	6·4	8·2	7·7	4·2	3·0	2·4	2·4
1900	3·2	3·1	5·3	7·2	5·7	7·8	8·0	6·5	5·6	5·1	2·2	2·5	2·2
Whole period.	3·0	3·1	4·3	7·2	5·7	6·7	6·4	6·5	5·0	4·2	2·2	2·2	2·2

Corresponding data are not given for V owing to their greater uncertainty. V ranges are on the average less than D or H ranges, and when very small they are

* ‘Phil. Trans.,’ A, vol. 208, p. 205.

exposed to undue uncertainty owing to the large temperature coefficient of the magnet and the absence of a temperature correction. The uncorrected temperature effect on R′ is of course not always in one direction, but amongst the least ranges of the month the chances are that some will be reduced by the temperature effect. Thus the natural consequence of the absence of a temperature correction will be to give too low a value for the monthly minimum range. The H ranges are not wholly free from this uncertainty, but the temperature coefficient of the H magnet is only about a seventh of that of the V magnet, while the average range in H is fully 80 per cent. in excess of that in V, thus the uncertainty is of quite a different order.

TABLE XLVII.—Horizontal Force. Absolute Daily Ranges. Smallest Values (Unit 1γ).

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
1890	16	18	17	31	25	26	31	24	23	25	16	13	13
1891	12	17	18	38	28	35	39	41	40	29	29	13	12
1892	26	36	37	30	41	44	46	45	36	38	19	17	17
1893	20	20	31	52	40	45	42	50	38	36	30	19	19
1894	21	30	25	36	46	60	50	49	31	36	22	19	19
1895	16	29	34	50	45	52	44	27	33	30	21	16	16
1896	24	29	23	43	35	35	29	33	48	23	15	12	12
1897	13	15	24	34	36	33	31	28	27	21	18	12	12
1898	10	13	29	16	23	33	28	25	33	23	18	11	10
1899	11	16	22	30	31	27	22	32	37	16	13	9	9
1900	12	12	21	25	26	29	23	22	22	14	11	7	7
Whole period	10	12	17	16	23	26	22	22	22	14	11	7	7

The D range is entirely free from this source of uncertainty, so far as is known ; it has the further advantage that no error can arise from an unrecognised variation in the scale value. There is, however, one slight drawback attending it, viz., that the force required to alter D by 1′ alters if H alters. Strictly speaking, the force equivalent to a change of 1′ in D is different at different times of a highly disturbed day.

The slight increase in accuracy that would result from allowing for changes in H in the course of a single day would be no adequate return for the labour involved. Apart from any disturbance effect, the force equivalent to a change of 1′ in D is influenced by secular change in H. The mean value of H in 1900 exceeded that in

1890 by 259γ, or about 1·4 per cent. If we go to 3 figures, the force required to alter D by 1′ was

$5·29\gamma$ in 1890 and 1891
$5·30\gamma$ „ 1892
$5·31\gamma$ „ 1893 and 1894
$5·32\gamma$ „ 1895
$5·33\gamma$ „ 1896
$5·34\gamma$ „ 1897 and 1898
$5·35\gamma$ „ 1899
$5·36\gamma$ „ 1900.

This variation, though quite appreciable when we are dealing with large ranges, is hardly worth considering in the case of the minimum ranges in Table XLVI.

Examining that table we see that the winter months, especially December, are conspicuous for small ranges. The fact that the mean values of R′ for winter months fall conspicuously short of those for other seasons is due, not so much to the absence of large values of R′, as to the presence of a considerable number of very small values. In summer, really small ranges are scarce. In fact, in the half year from April to September no single day of the 11 years had a range under 5′. In 1893 no April day had a range under 12′·5, though the mean value for the month was only 17′·1, and in June the lowest range was 12′·3 though the mean for the month was only 16′·4. The uniformity of the range in June 1893 was very remarkable. In 21 of the 30 days the range lay between 14′·0 and 18′·5 and the highest value of the month was only 21′·6. The absolutely smallest range of the 11 years was 2′·2, or 12γ in force.

Turning to Table XLVII., we see that the lowest range recorded was 7γ. The winter months, as with D, supply all the outstandingly small ranges, December being especially conspicuous.

During the eleven years the sensitiveness of the Kew H magnetograph was always near 1 mm. = 5γ. Thus a range of 7γ implies a variation of only 1·4 mm. in the length of the ordinate throughout a portion of curve whose length of abscissa is 360 mm. This means a slope so gentle everywhere that the recognition of the positions of the maximum and minimum is no easy matter. Again, a change of 1° F. in temperature would alter the ordinate fully 0·3 mm. Thus not improbably 7γ may have been somewhat an under-estimate of the true minimum range.

At the other end of the scale the largest observed ranges were

in D, 1° 25′·6 ($\equiv 457\gamma$) on March 15, 1898;
in H, 720γ on February 13, 1892;
in V, 639γ on July 20, 1894.

It is possible that the D range on March 15, 1898, may have been exceeded on

February 14, 1892, as the trace then went beyond the limit of registration, and the range measured to the edge of the sheet was 1° 19′. If we accept the value on March 15, 1898, as the true maximum, we find maximum range/minimum range = 102·9 in H, as compared with 39·4 in D.

§ 29. Tables XLVIII. to LIII. deal with the frequency of occurrence of ranges of different size for D, H, and V. There are two tables for each element, the one showing the distribution for each of the 11 years, the other the distribution for each of the 12 months. To make the D results comparable with those for the force elements, the same force limits are employed for the several classes. It was not necessary to convert individual D ranges into their equivalents in force, but only to find what were the angles corresponding to the several force limits, employing the relation between 1′ and 1γ appropriate to the particular year.

TABLE XLVIII.—Declination Ranges (Unit 1γ). Number of Occurrences.

Year.	From 0 To 12·5	12·5 25	25 37·5	37·5 50	50 62·5	62·5 75	75 100	100 125	125 150	150 175	175 200	200 250	250 500	500
1890	0	4	55	96	96	68	30	11	4	1	0	0	0	0
1891	0	13	27	35	78	75	80	37	8	5	4	2	1	0
1892	0	1	9	28	49	70	115	39	18	12	9	8	8	0
1893	0	3	13	26	33	61	156	47	15	8	2	0	1	0
1894	0	2	10	36	41	92	107	36	15	4	7	3	12	0
1895	0	6	18	27	49	70	112	41	19	16	7	0	0	0
1896	0	8	26	36	65	82	75	36	18	11	3	5	1	0
1897	1	15	37	57	93	74	45	31	6	2	1	1	2	0
1898	0	17	39	52	102	66	52	22	8	2	2	0	3	0
1899	0	26	38	70	93	64	50	12	3	5	2	2	0	0
1900	1	49	49	96	102	45	14	3	3	3	0	0	0	0

TABLE XLIX.—Declination Ranges (Unit 1γ). Number of Occurrences in Eleven Years.

Month.	From 0 To 12·5	12·5 25	25 37·5	37·5 50	50 62·5	62·5 75	75 100	100 125	125 150	150 175	175 200	200 250	250 500	500
January. . .	0	38	67	74	51	30	37	23	10	6	1	3	1	0
February . .	0	21	43	52	44	42	54	26	9	7	4	3	5	0
March. . . .	0	1	11	39	71	68	67	36	24	14	3	1	6	0
April	0	0	0	25	74	85	90	32	12	5	5	1	1	0
May.	0	0	6	40	61	82	97	29	14	4	1	5	2	0
June	0	0	2	35	88	89	84	23	2	4	0	3	0	0
July.	0	0	2	32	96	97	80	19	3	4	2	3	3	0
August . . .	0	0	1	19	86	93	110	24	4	2	0	0	2	0
September .	0	0	8	36	81	70	87	23	11	3	7	1	3	0
October . . .	0	1	21	69	66	43	68	45	13	8	7	0	0	0
November .	1	30	64	70	50	40	32	16	8	10	6	1	2	0
December. .	1	53	96	68	33	28	30	19	7	2	1	0	3	0

TABLE L.—Horizontal Force Ranges (Unit 1γ). Number of Occurrences.

Year.	From 0 To 12·5	12·5 25	25 37·5	37·5 50	50 62·5	62·5 75	75 100	100 125	125 150	150 175	175 200	200 250	250 500	500
1890	0	40	99	111	66	28	14	5	2	0	0	0	0	0
1891	1	23	49	68	82	52	59	14	11	3	1	1	1	0
1892	0	4	33	66	61	60	68	29	16	4	3	9	10	3
1893	0	10	32	50	81	68	78	25	13	5	0	3	0	0
1894	0	8	44	38	59	71	79	32	12	5	4	2	9	2
1895	0	9	38	57	77	66	68	30	10	8	2	0	0	0
1896	2	26	42	68	72	51	60	26	11	3	3	0	2	0
1897	1	34	69	99	78	39	27	9	6	2	1	0	0	0
1898	3	46	58	80	67	46	41	17	2	1	1	1	0	2
1899	4	45	83	79	69	37	33	9	5	1	0	0	0	0
1900	15	73	117	106	32	11	7	1	1	1	0	1	0	0

TABLE LI.—Horizontal Force Ranges (Unit 1γ). Number of Occurrences in Eleven Years.

Month.	From 0 To 12·5	12·5 25	25 37·5	37·5 50	50 62·5	62·5 75	75 100	100 125	125 150	150 175	175 200	200 250	250 500	500
January . . .	5	73	97	58	32	32	22	12	7	0	1	1	1	0
February . .	1	45	73	48	49	30	30	14	11	1	2	1	3	2
March . . .	0	12	71	71	68	32	38	21	15	2	2	3	5	1
April	0	2	29	73	64	66	62	19	4	6	2	2	1	0
May	0	1	36	64	80	64	60	18	6	4	2	2	4	0
June	0	0	29	75	78	58	55	14	13	4	1	2	1	0
July	0	2	38	69	78	49	61	24	9	3	1	3	3	1
August . . .	0	5	23	77	94	56	53	21	4	3	1	2	0	2
September .	0	5	32	76	79	52	55	16	7	3	1	0	3	1
October . . .	0	15	61	79	46	48	66	21	1	2	2	0	0	0
November .	3	67	78	78	47	18	17	9	9	3	0	0	1	0
December .	17	91	97	54	29	24	15	8	3	2	0	1	0	0

TABLE LII.—Vertical Force Ranges (Unit 1γ). Number of Occurrences.

Month.	From 0 To 12·5	12·5 25	25 37·5	37·5 50	50 62·5	62·5 75	75 100	100 125	125 150	150 175	175 200	200 250	250 500	500
1890	71	164	111	13	5	1	0	0	0	0	0	0	0	0
1891	26	110	143	39	22	7	7	5	4	1	0	0	1	0
1892	13	96	126	58	17	12	15	8	3	3	2	3	9	1
1893	6	106	126	75	23	9	13	3	1	1	1	1	0	0
1894	15	96	134	52	26	12	10	3	2	1	2	3	7	2
1895	13	101	136	53	31	12	13	5	1	0	0	0	0	0
1896	18	127	127	40	21	10	13	7	1	0	1	1	0	0
1897	51	144	119	26	13	2	7	0	2	1	0	0	0	0
1898	37	132	133	40	13	3	3	1	0	0	0	0	2	1
1899	45	170	108	27	5	3	6	0	1	0	0	0	0	0
1900	61	199	94	6	3	0	0	0	0	1	0	0	1	0

TABLE LIII.—Vertical Force Ranges (Unit 1γ). Number of Occurrences in Eleven Years.

Month.	From 0 To 12·5	12·5 25	25 37·5	37·5 50	50 62·5	62·5 75	75 100	100 125	125 150	150 175	175 200	200 250	250 500	500
January. . .	76	173	58	14	11	4	4	0	0	1	0	0	0	0
February . .	42	133	74	23	14	5	8	4	0	0	2	1	3	1
March. . . .	5	124	118	37	22	6	14	6	0	3	0	0	5	1
April	1	74	163	51	15	5	14	3	2	1	0	0	1	0
May.	0	43	171	67	33	10	5	2	2	2	1	2	3	0
June	0	76	169	48	14	12	5	2	1	0	1	1	1	0
July.	0	86	166	48	14	10	8	2	1	0	1	3	1	1
August . . .	2	111	158	46	11	1	5	2	1	1	0	1	1	1
September .	9	139	108	37	14	5	9	3	3	0	0	0	3	0
October. . .	22	168	91	25	17	8	5	4	1	0	0	0	0	0
November .	74	176	38	19	5	3	7	4	2	0	1	0	1	0
December .	125	142	43	14	9	2	3	0	2	0	0	0	1	0

The step for the six lowest classes is only $12\cdot5\gamma$, answering roughly to $2'\cdot5$ in D, or half the step employed in the corresponding tables in my previous paper. For the next five classes the step is 25γ. The twelfth class has a step of 50γ, the thirteenth of 250γ, while the last class includes the few ranges—none in D—which exceeded 500γ. It requires a large number of classes to show the distribution satisfactorily near the lower end of the scale. Towards the upper end of the scale, the occurrences are so few that the employment of a very large number of classes with small steps would have been a useless complication. It would, in fact, require a very much longer period of years to fix the exact law of incidence for ranges exceeding 200γ. To facilitate intercomparison, Table LIV. includes results for the whole year from the three elements. The 11 years, the four years representing sunspot maximum, and the three years representing sunspot minimum are treated separately. Table LIV. likewise gives results from the three elements for the three seasons, derived from the whole 11 years.

The results in Table LIV. are shown graphically in fig. 13. The number of days in each class was expressed as a percentage of the total number of days included in all the classes, and ordinates were drawn proportional to these percentages, due allowance being made for the difference between the steps in the earlier and later classes. The graphical representation was not carried beyond the 9th class, whose superior limit is 150γ, because the ordinates for the higher classes would have been too short to show satisfactorily, and the irregularities arising from insufficient length of period would have been too great. In all the curves the range of greatest frequency of occurrence is less than the arithmetic mean range. Also the range of most frequent occurrence is always greater for D than for H, and much larger for H than for V. On many days when the D and H curves show large irregular

TABLE LIV.—Ranges (Unit 1γ). Number of Occurrences.

Period or season.	Element.	From 0 To 12·5	12·5 25	25 37·5	37·5 50	50 62·5	62·5 75	75 100	100 125	125 150	150 175	175 200	200 250	250 500	500
Year. 11 years (4017 days)	D H V	2 26 356	144 318 1445	321 664 1357	559 822 429	801 744 179	767 529 71	836 534 87	315 197 32	117 89 15	69 33 8	37 15 6	21 17 8	28 22 20	0 7 4
Year. 1892 to 1895 (1461 days)	D H V	0 0 47	12 31 399	50 147 522	117 211 238	172 278 97	293 265 45	490 293 51	163 116 19	67 51 7	40 22 5	25 9 5	11 14 7	21 19 16	0 5 3
Year. 1890, 1899, 1900 (1095 days)	D H V	1 19 177	79 158 533	142 299 313	262 296 46	291 167 14	177 76 3	94 54 6	26 15 0	10 8 1	9 2 1	2 0 0	2 1 0	0 0 1	0 0 0
Winter (1322 days)	D H V	2 26 317	142 276 624	270 345 213	264 238 70	178 157 39	140 104 14	153 84 22	84 43 8	34 30 4	25 6 1	12 3 3	7 3 1	11 5 5	0 2 1
Equinox (1342 days)	D H V	0 0 37	2 34 505	40 193 480	169 299 150	292 257 68	266 198 24	312 221 42	136 77 16	60 27 6	30 13 4	22 7 0	3 5 0	10 9 9	0 2 1
Summer (1353 days)	D H V	0 0 2	0 8 316	11 126 664	126 285 209	331 330 72	361 227 33	371 229 23	95 77 8	23 32 5	14 14 3	3 5 3	11 9 7	7 8 6	0 3 2

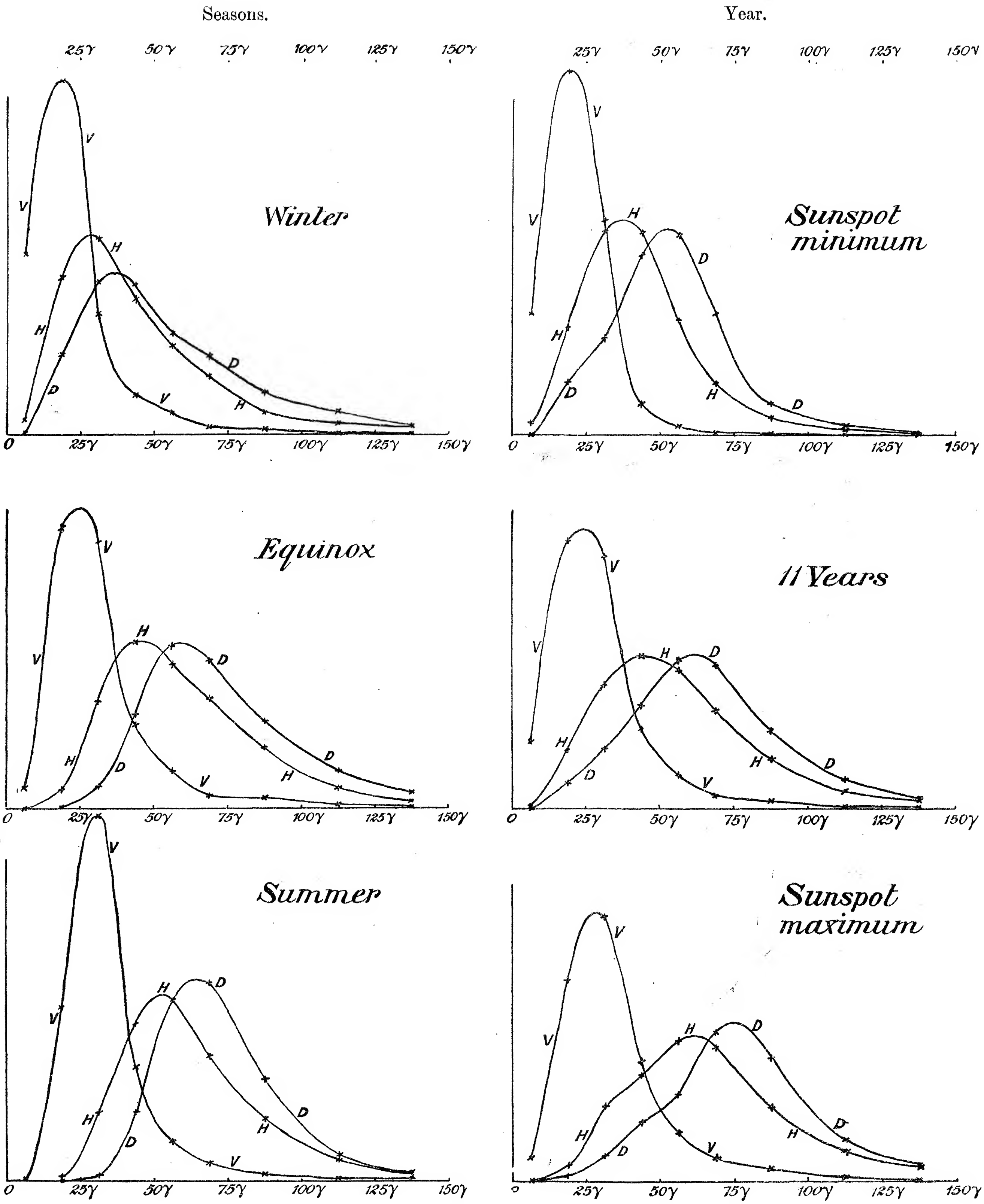

Fig. 13. Absolute daily ranges, frequency of occurrence.

oscillations, the V curve shows practically no trace of disturbance, or merely a slight exaggeration of the afternoon maximum. At times, however, V exhibits disturbances rivalling those in D and H. If we confine ourselves to days when the range exceeded 250γ, there were 24 occurrences in V as compared with 28 in D, and on 4 occasions the V range exceeded 500γ, while the largest D range observed was 457γ. During some of these very large disturbances the V trace—which has usually a gently rounded contour—showed large rapid oscillations just like the D and H traces.

The great majority of the largest storms occurred in 1892 or 1894. In the group of years of sunspot minimum a range as high as 250γ appeared only once in V, and on no single occasion in D or H.

There is a certain resemblance between the frequency curves for winter and for the sunspot minimum year, between those for equinox and for the average year, and again between those for summer and for the sunspot maximum year. The curves for the sunspot maximum year show a less smooth rise to the maximum ordinate than the others.

§ 30. Fig. 14 presents the range distribution data from a different point of view. Unit abscissa represents the arithmetic mean range for the element and season considered. Thus, in the case of the year from the 11 years, it represents $72{\cdot}2\gamma$ in D, $60{\cdot}7\gamma$ in H, and $32{\cdot}9\gamma$ in V. This eliminates the effect of mere size, and so helps to bring out the degree of resemblance between the laws of distribution followed in different elements, or in the same element at different seasons. In the case of the whole year, the range of greatest frequency occurs very nearly at the same place—*i.e.*, bears very nearly the same ratio to the mean range—in the H and V curves; in D it answers to a decidedly larger abscissa.

In the case of H, the range of greatest frequency answers to a higher and higher fraction of the mean range as we pass from winter to equinox, and from equinox to summer. There is not much difference between the curves in fig. 14 answering to sunspot maximum and minimum, though the mean ranges are respectively $75{\cdot}8\gamma$ and $43{\cdot}9\gamma$.

All the frequency curves have the general aspect of the ordinary diagram of intensity of visible and invisible radiation from a solid at high temperature. This, however, may mean no more than that the number of classes in which the ranges were grouped was too limited to show the existence of bands of reduced frequency or of no frequency. The existence of such bands, at least towards the side of the very high ranges, is by no means improbable, especially if storms should prove to have more than one origin.

For the careful measurement of the curves and the calculation of the hourly means I am indebted to various members, past and present, of the Kew Observatory staff. Amongst these I would particularly mention Messrs. G. BADDERLY and C. COOPER,

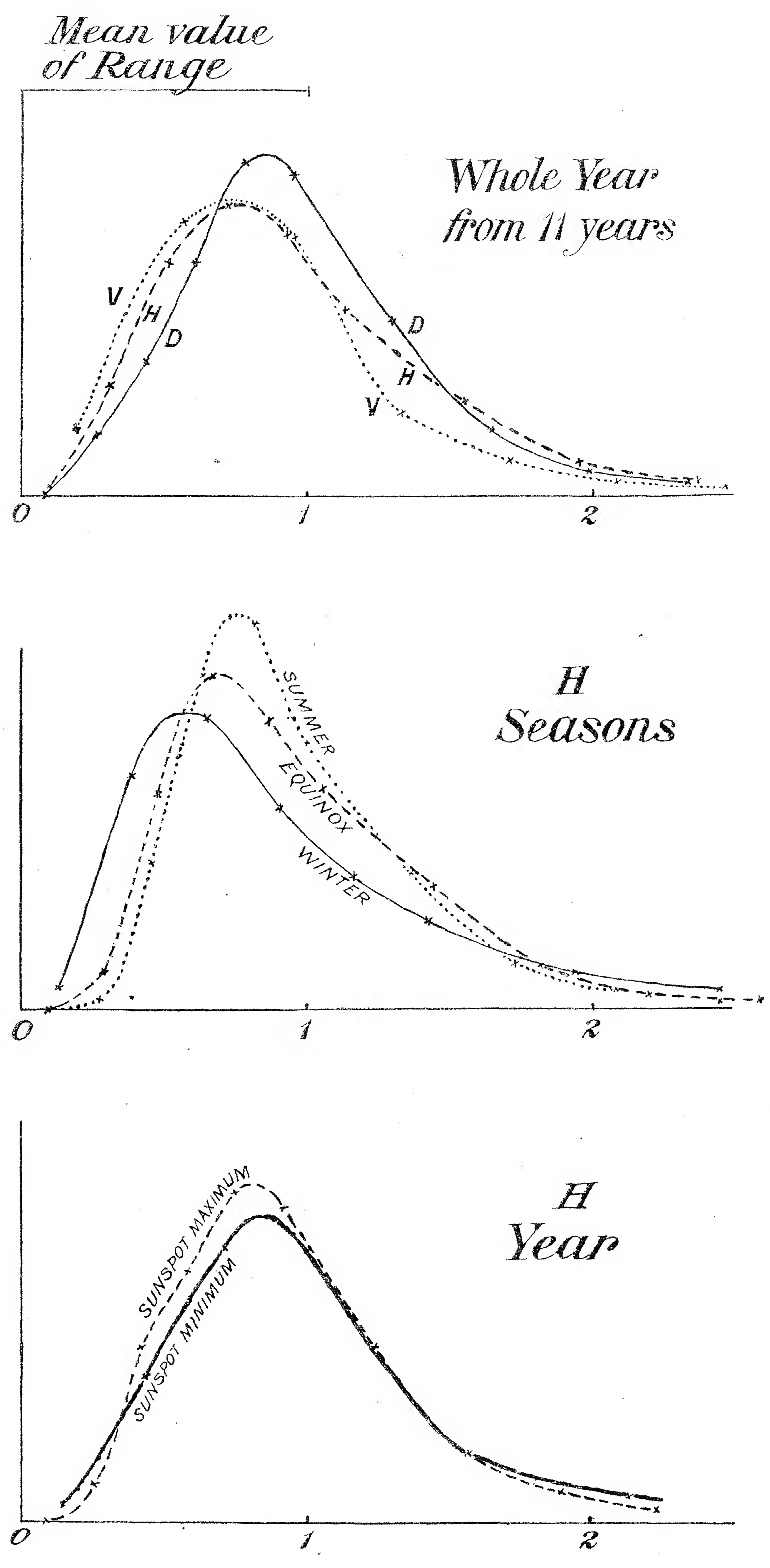

Fig. 14. Absolute daily ranges frequency of occurrence.

now of the National Physical Laboratory, and Mr. B. FRANCIS, the present magnetic observer at Kew Observatory. During the eleven years whose records are mainly considered the magnetographs were under the charge of Mr. T. W. BAKER, then Chief Assistant, who also took the great majority of the absolute observations. The homogeneousness of the material owes much to Mr. BAKER. The expense of measuring the curves was defrayed mainly out of grants from the Government Grant Committee. The calculation of the diurnal inequalities, Fourier coefficients, and other arithmetical work has been mainly done in my leisure hours.